FDS - The Fornax Ultra-Deep Imaging Survey

Peletier, Reynier; Team, FDS

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SUNDIAL
H2020 Innovative Training Network

FDS – the FORNAX ultra-Deep imaging Survey

Evolution of Dwarf Galaxies

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Kapteyn Institute
University of Groningen

and the FDS-Team

Contents of this talk:

1. Introduction

2. The FDS Survey

3. Evolution of Dwarf Galaxies in Fornax – new results from FDS

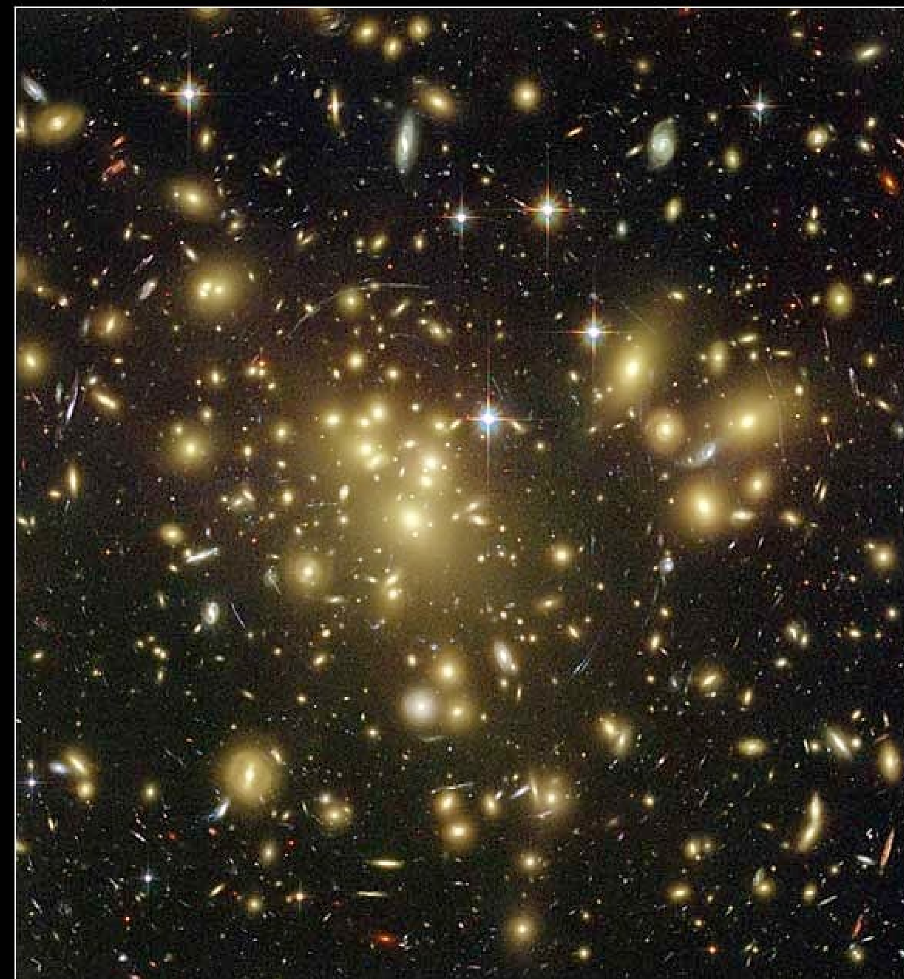
4. Other FDS-related projects on Faint Galaxies

Galaxies in “field” vs. “cluster”

Hubble Ultra Deep Field
Hubble Space Telescope • Advanced Camera for Surveys

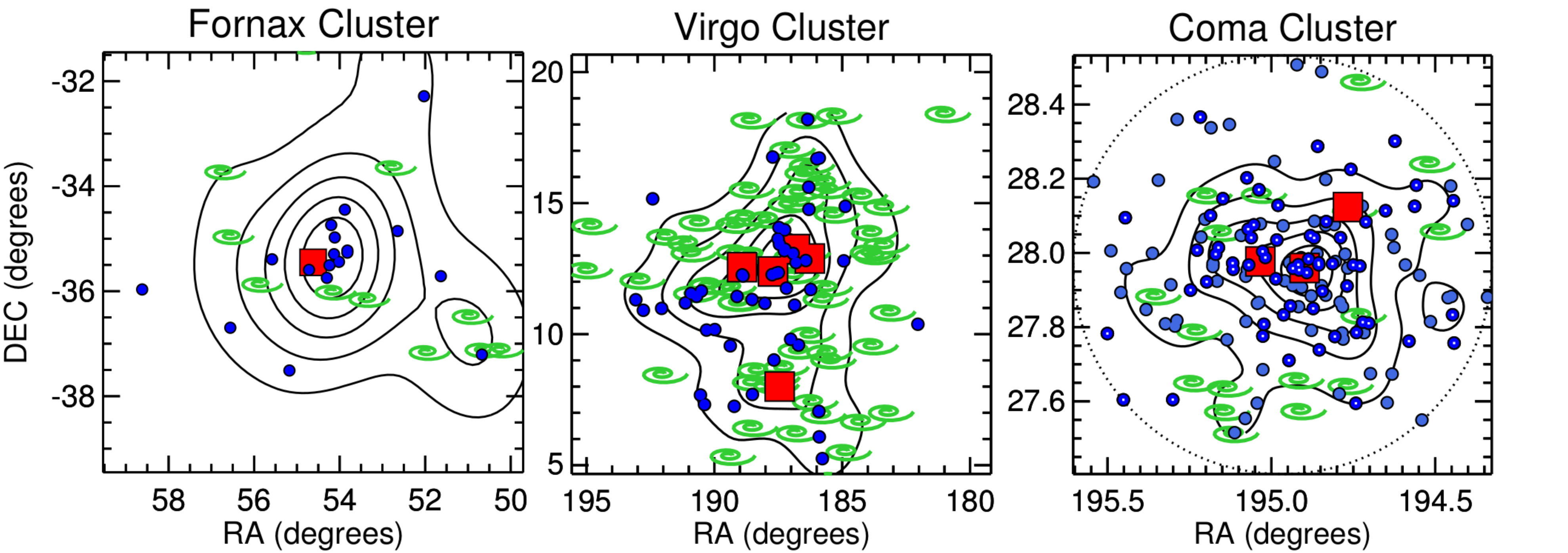
NASA, ESA, S. Beckwith (STScI) and the HUDF Team STScI-PRC04-07a

Galaxy Cluster Abell 1689 **HST** ▪ ACS



NASA, N. Benitez (JHU), T. Broadhurst (Hebrew Univ.), H. Ford (JHU), M. Clampin(STScI), G. Hartig (STScI), G. Illingworth (UCO/Lick Observatory), the ACS Science Team and ESA STScI-PRC03-01a

The strong morphology-density relation in nearby galaxy clusters shows that the environment is very important in shaping galaxies



(Cappellari 2016)

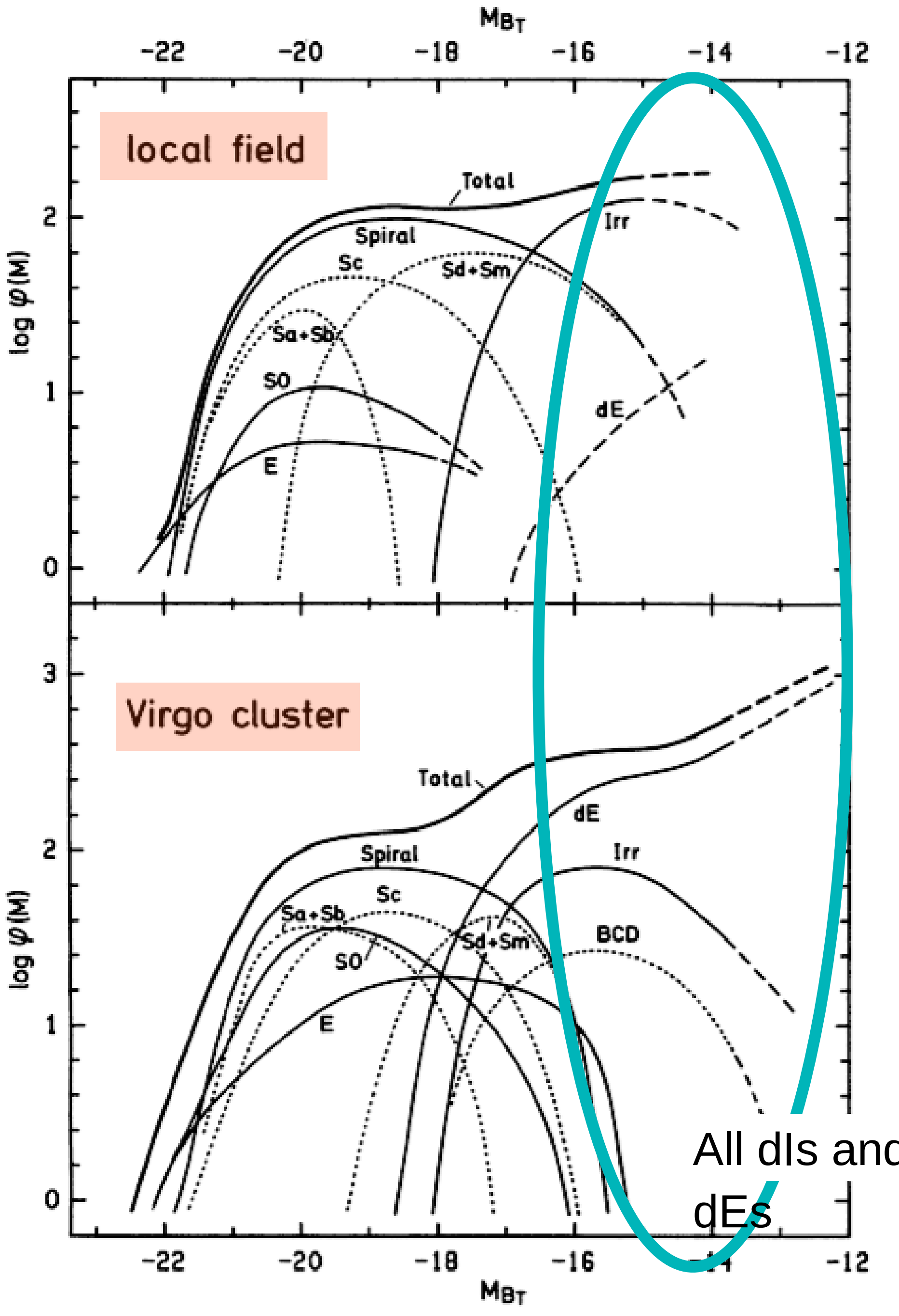
The Luminosity Function differs strongly between cluster and field

→ Dwarfs are excellent probes to study the role of the environment on the evolution of galaxies

– Dwarfs are faint, so need to be studied in the nearby Universe

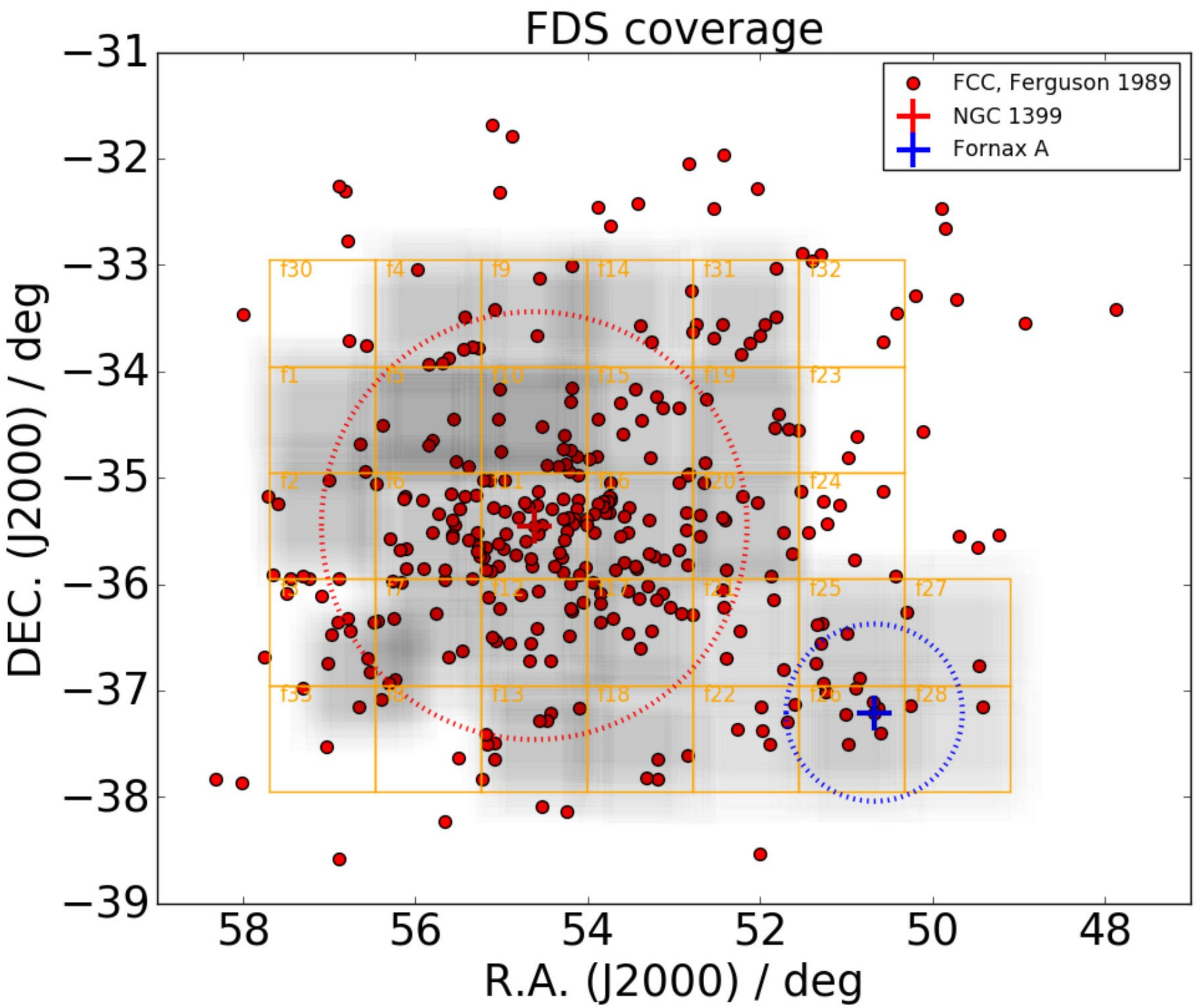
– Largest nearby clusters: Virgo and Fornax. Virgo is being studied using the NGVS survey (Ferrarese et al. 2012).

– For Fornax we have set up the **Fornax Deep Survey (FDS)**



Binggeli, Sandage, Tammann ARAA (1988) ARAA ,26, 509

The FDS Fornax Ultradeep Survey ESO/VST



INTEGRATION TIMES

u' – 11000s
g' – 8000s
r' – 8000s
i' – 5000s

DEPTH (SB, 1σ)

u' – 28.0
g' – 28.6
r' – 28.1
i' - 27.2

ASTRO WISE

FDS: Observations finished Nov 2017, data reduction finished March 2018 by Aku Venhola; NGC 1316 (Fornax A) area reduced by VSTTUBE (Naples).

The Fornax Deep Survey

Collaboration based on VST OmegaCAM GTO time of

INAF-OAC Naples

and

NOVA/ Kapteyn

university of groningen
faculty of science and engineering
kapteyn astronomical institute

NOVA

FDS Core Members

Massimo Capaccioli

Raffele D'Abrusco

Aniello Grado

Jesus Falcon Barroso

Michael Hilker

Thorsten Lisker

Steffen Mieske

Nicola Napolitano

Maurizio Paolillo

Marilena Spavone

Edwin Valentijn

Glenn van de Ven

Aku Venhola

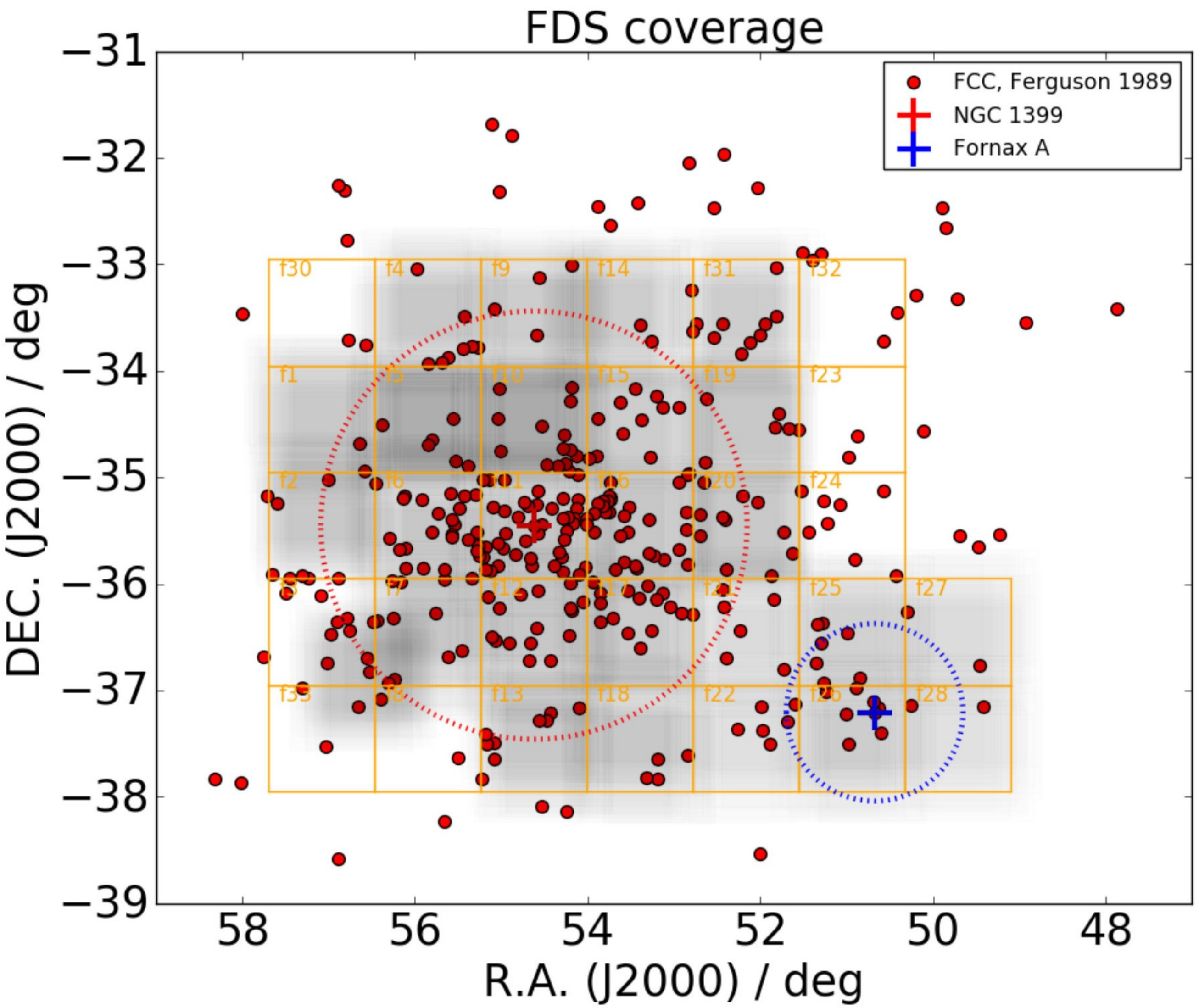
Gijs Verdoes Kleijn

Carolin Wittmann

PI's: Peletier (Kapteyn) and Iodice (INAF-OAC)

FDS Meeting Groningen (Sep 17, 2017) - The Participants

The FDS Fornax Ultradeep Survey ESO/VST



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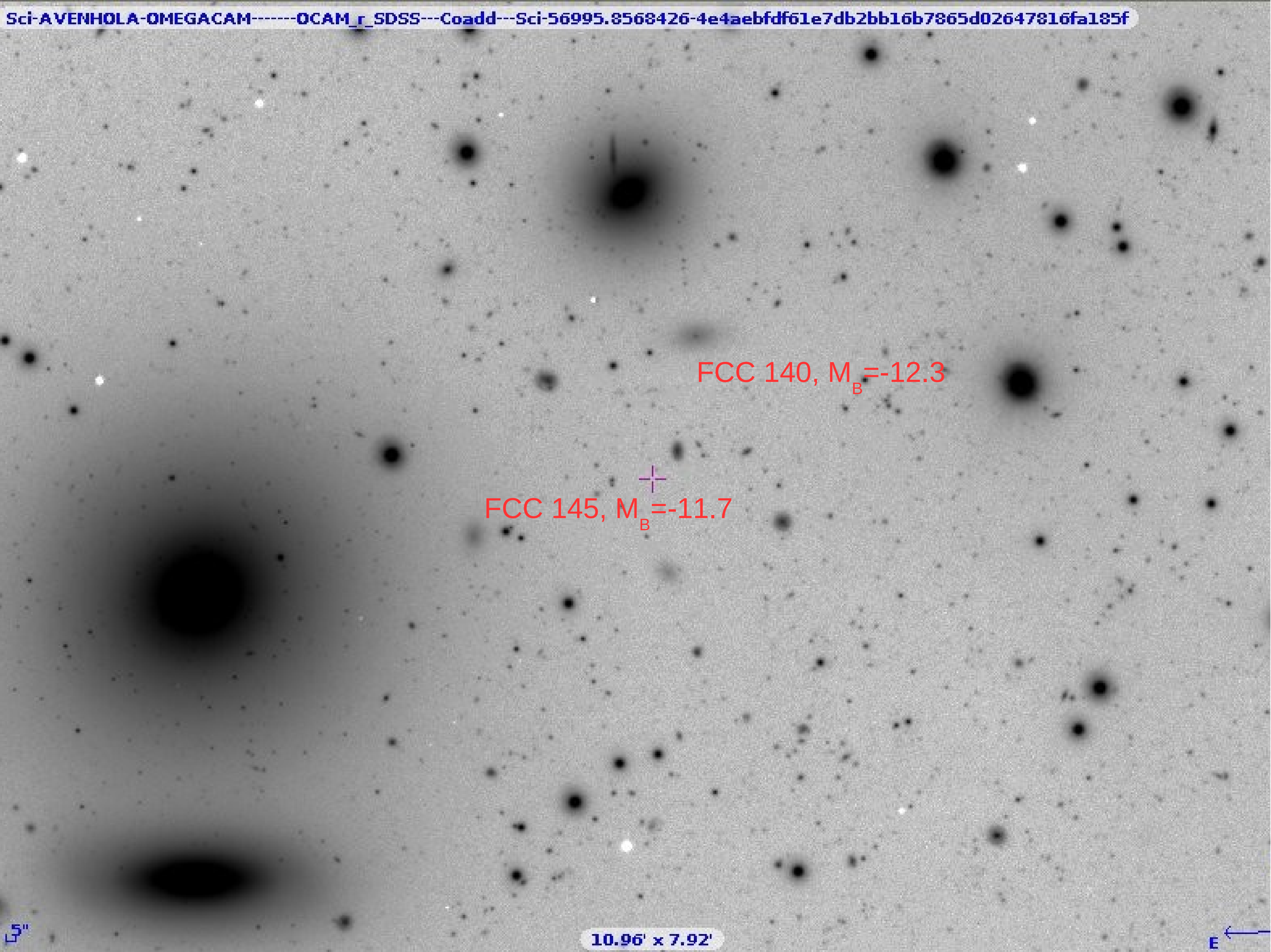
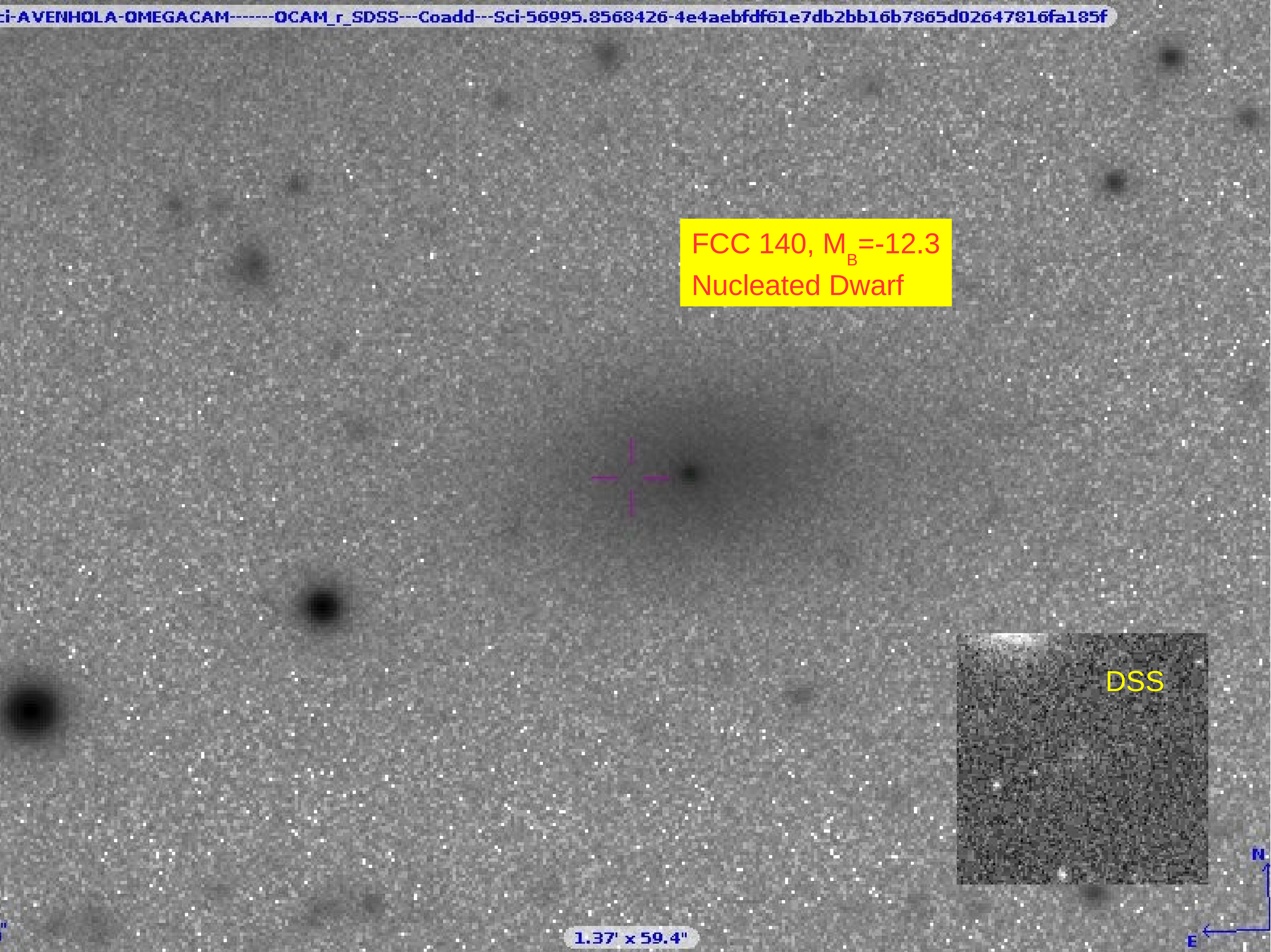
FDS: Observations finished Nov 2017, data reduction finished March 2018 by Aku Venhola; NGC 1316 (Fornax A) area reduced by VSTTUBE (Naples).



Sci-AVENHOLA-OMEGACAM-------OCAM_r_SDSS---Coadd---Sci-56995.8568426-4e4aebfdf61e7db2bb16b7865d02647816fa185f
FCC 140, M_B=-12.3
FCC 145, M_B=-11.7
5"
10.96' x 7.92'
E

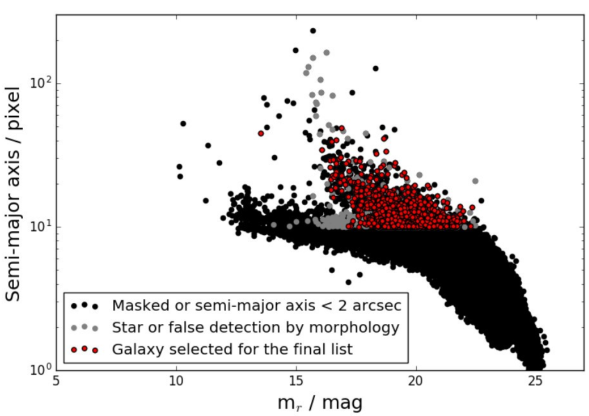

ci-AVENHOLA-OMEGACAM-------OCAM_r_SDSS---Coadd---Sci-56995.8568426-4e4aebfdf61e7db2bb16b7865d02647816fa185f
FCC 140, M_B=-12.3
Nucleated Dwarf
DSS
N
E
1.37' x 59.4"

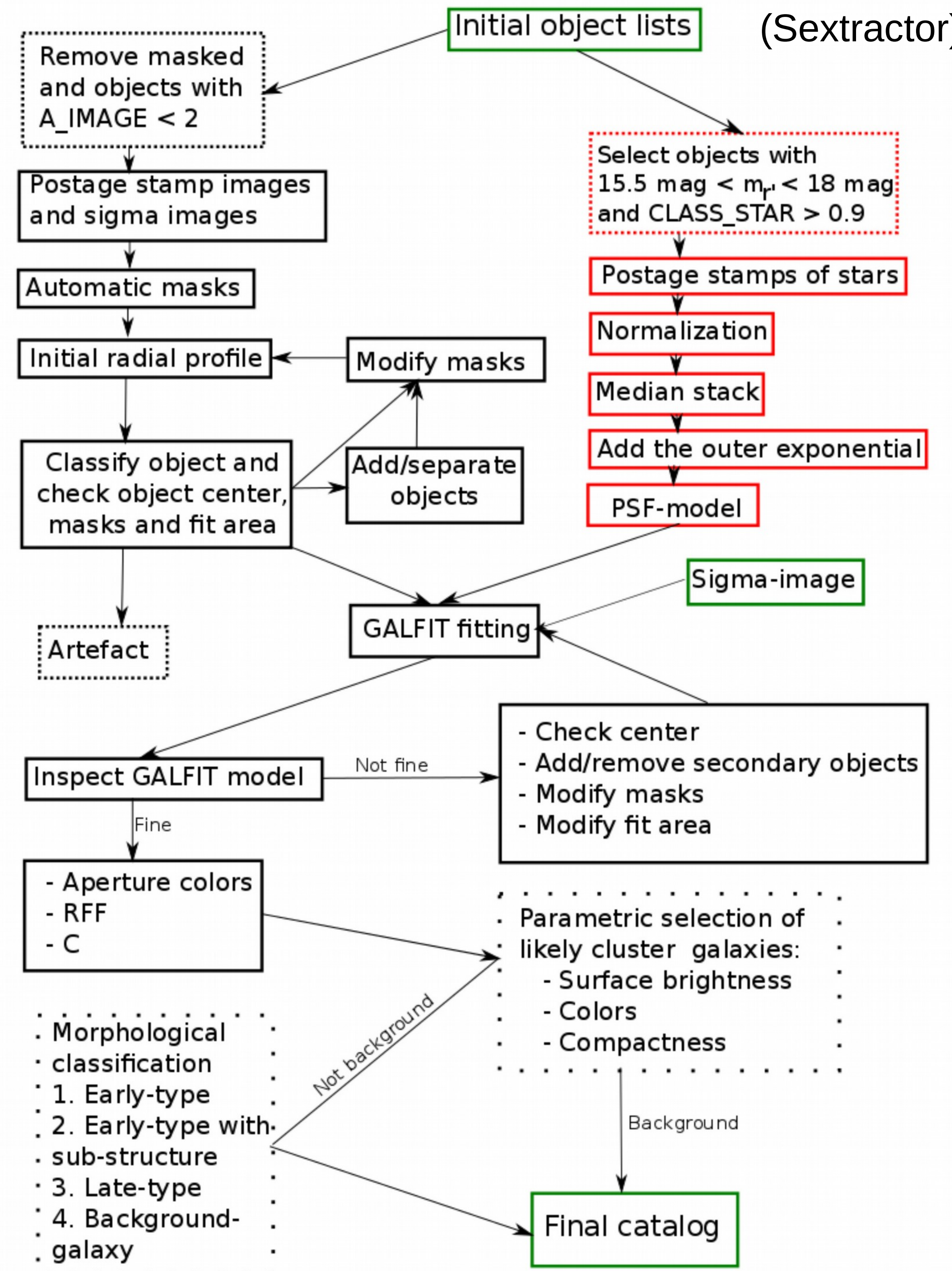
Making the Dwarf Catalog (Venhola et al. 2018a)

Constraints:

- No objects near bright saturated stars

- No objects with size < 2'' (A_IMAGE)





Selecting Cluster Members (1):

Spectroscopically confirmed members
(Drinkwater et al. 2002):

Red: Early-type galaxies
Blue: Late-type galaxies
Green: Background galaxies

1. Color cut.

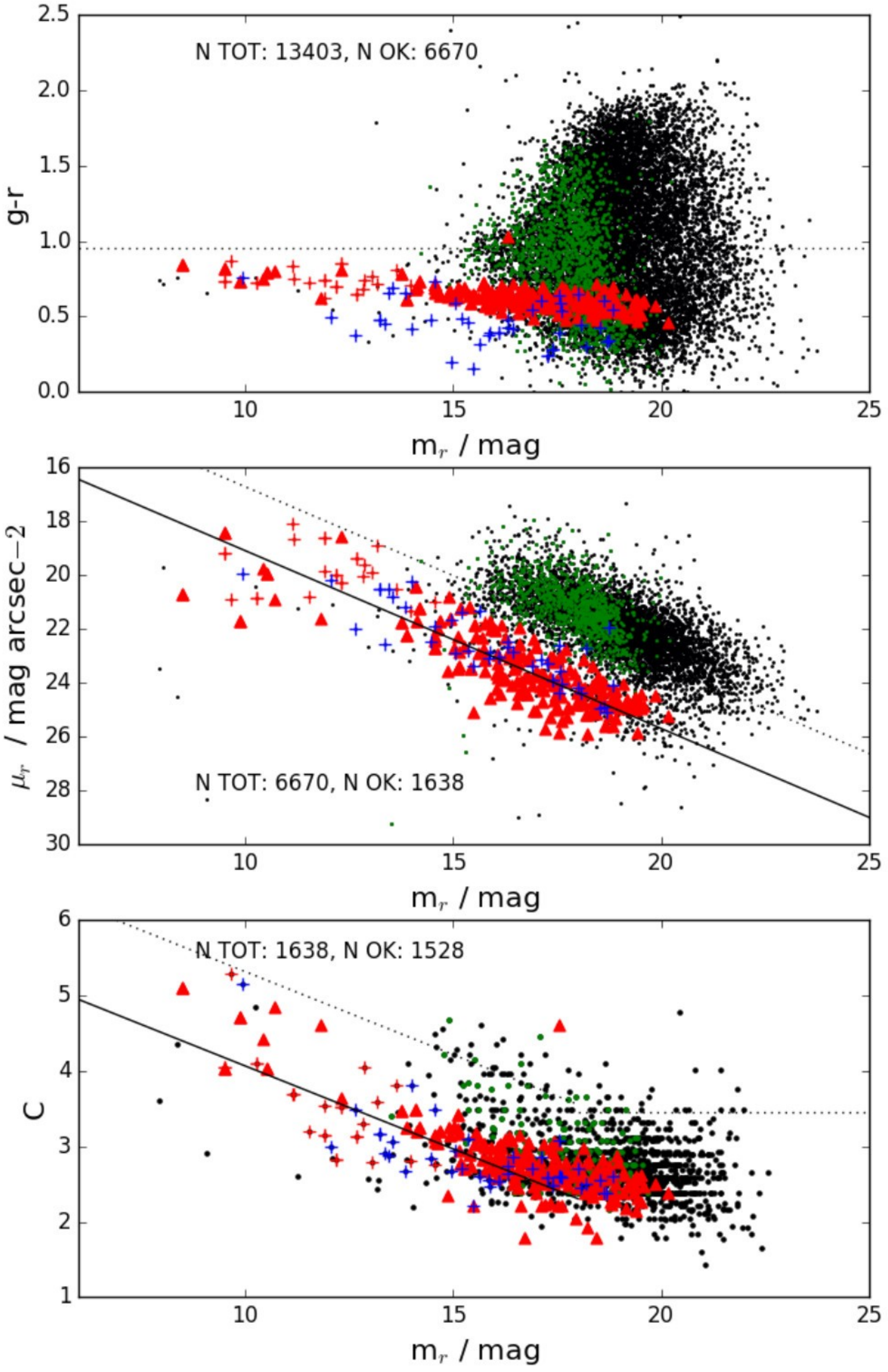
Remove objects redder than reddest
spectroscopically confirmed object + 0.1
(g-r>0.95)

2. Surface brightness cut.

Remove objects more than 3 sigma away
From magnitude – surface brightness fit
To cluster members; this works, since background
Galaxies generally have higher surface brightness.

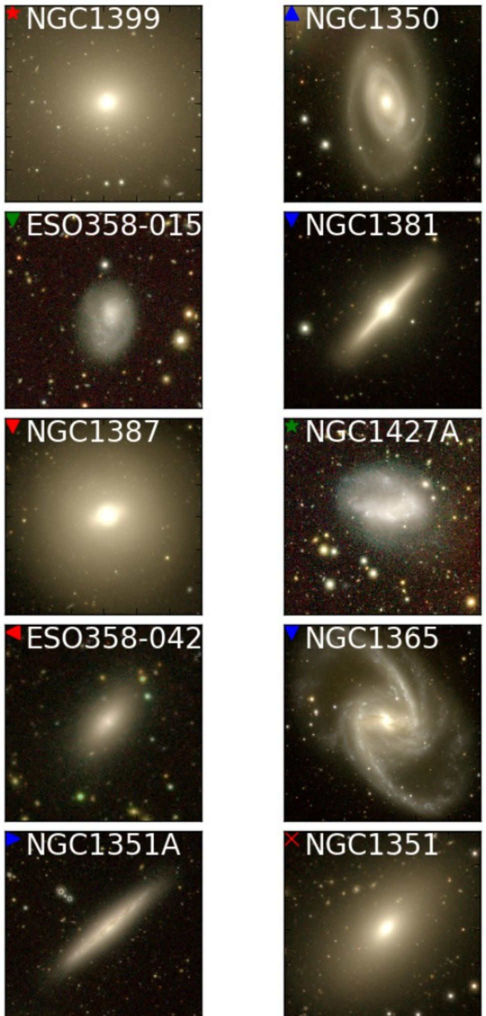
3. Compactness cut.

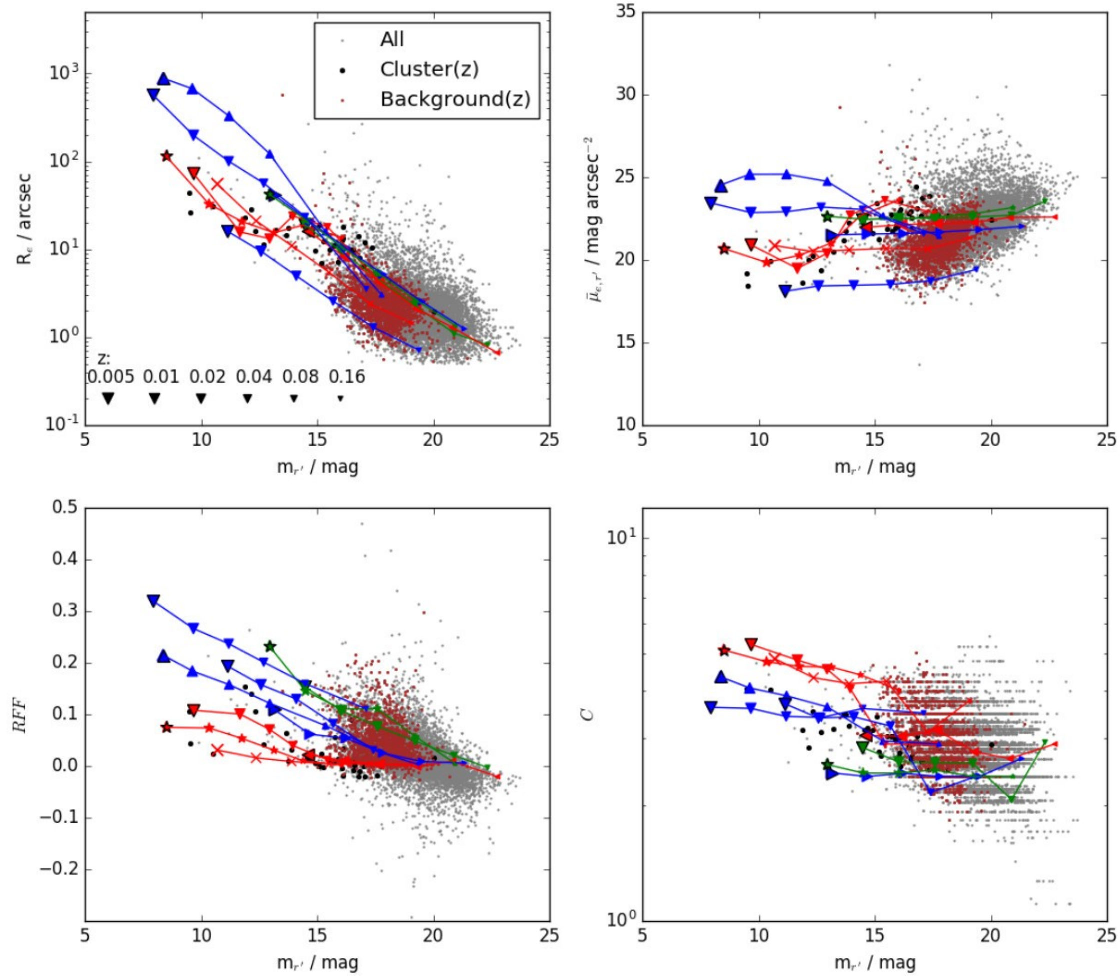
Remove galaxies in a region in the magnitude -
compactness diagram that cannot be reached
by cluster galaxies



Selecting Cluster Members (2):

Using the RFF Parameter (Hoyos et al. 2011), a parameter measuring smoothness of a galaxy image, corrected for noise.





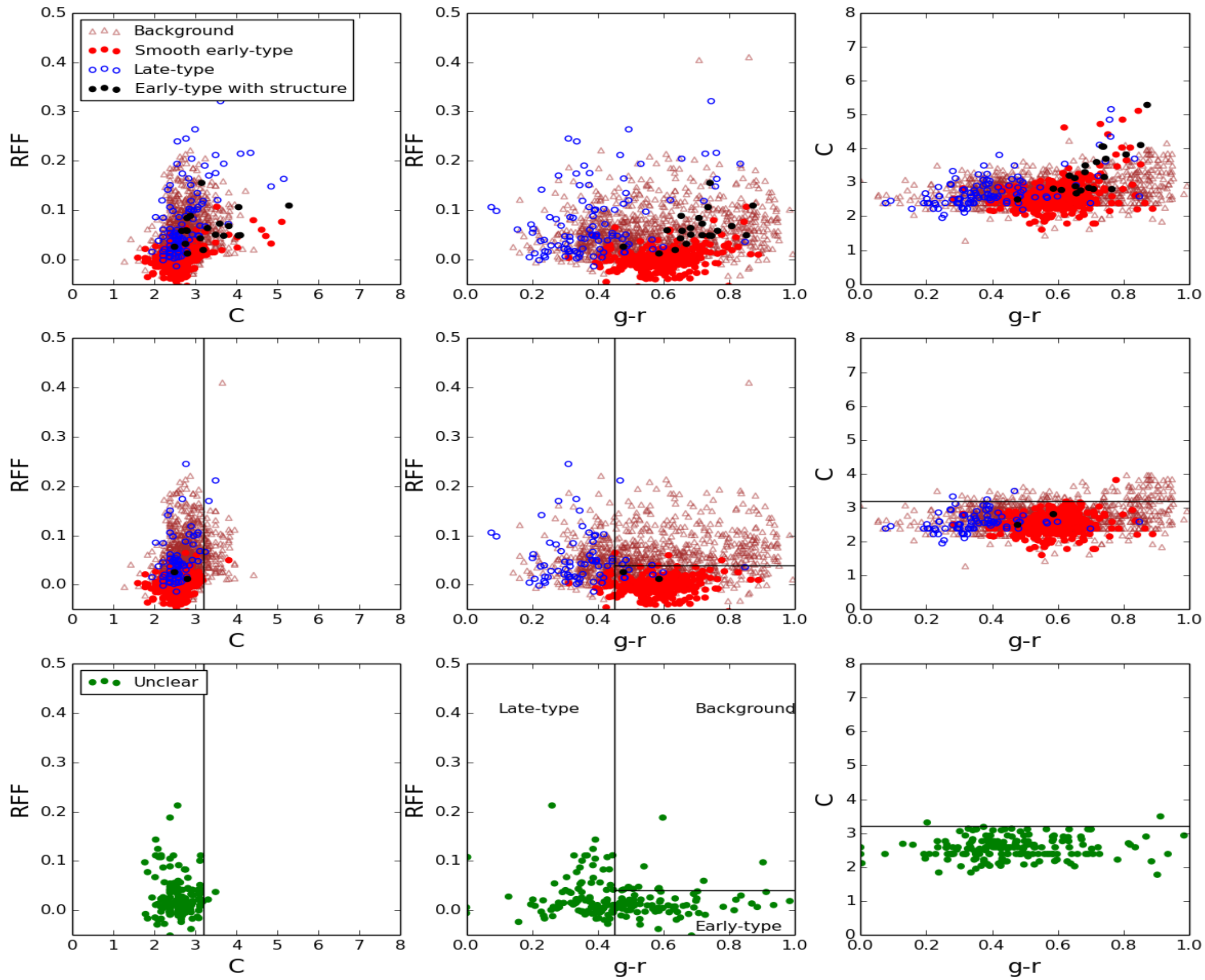
$$RFF = \frac{\sum_{i=1}^{n_{r<R_P}} (|data_i - model_i| - 0.8\sigma_i)}{F_{r<R_P}}$$

Selecting Cluster Members (3):

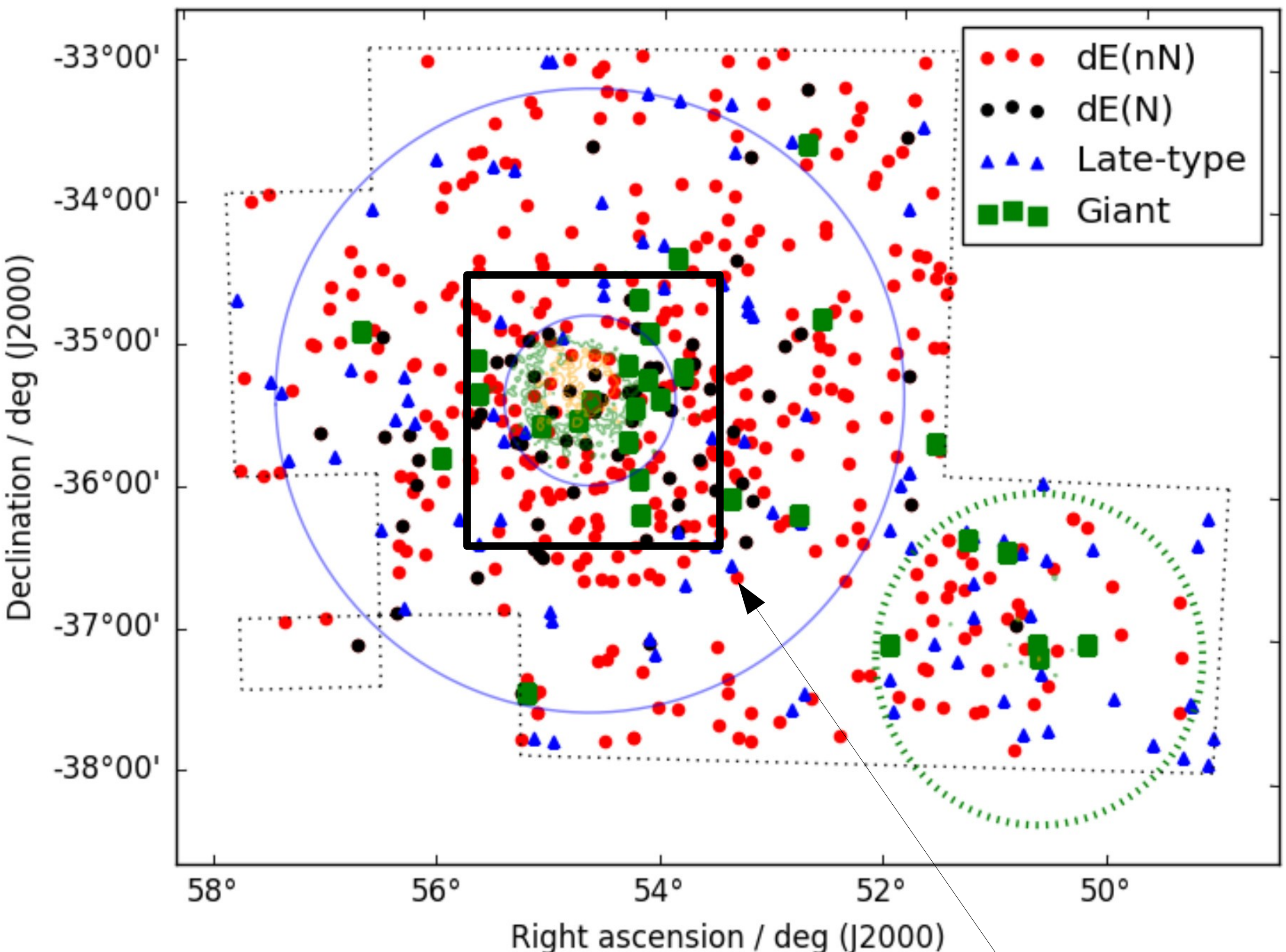
All spectroscopically confirmed cluster members

Dwarf galaxies (m_r>15) + background

Candidates + suggested Cuts in C and RFF



The FDS Galaxy Survey



Peletier et al. 2018
(main survey definition)

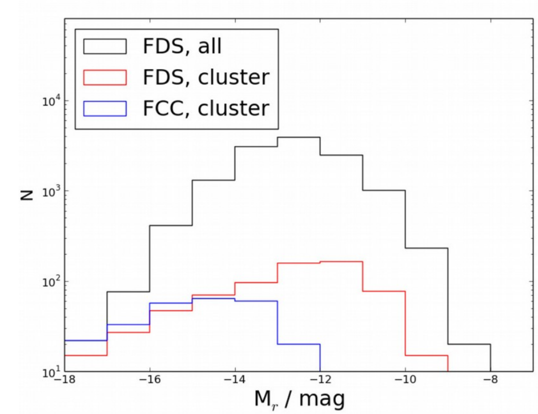
Iodice et al. 2018
(large early-type gals.)

Venhola et al. 2018
(Dwarf Catalog)

Venhola et al. 2018
(Dwarf Science)

Venhola et al. 2018
(Ultra Diffuse Galaxies)

Etc.



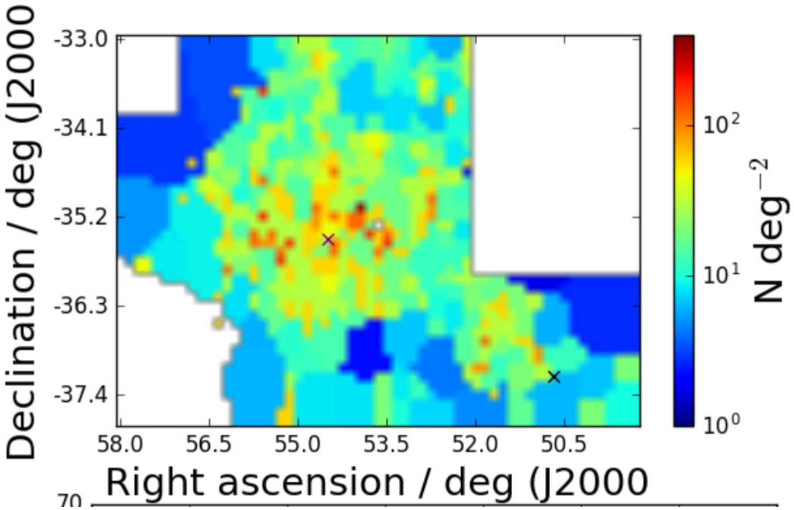
668 cluster galaxies
476 early-type
192 late-type

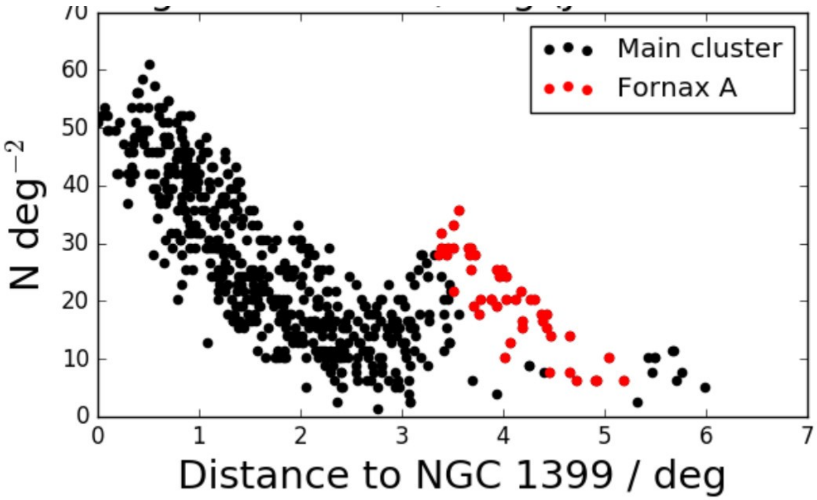
AREA: 26 deg^2

(cf: NGVS 104 deg^2)

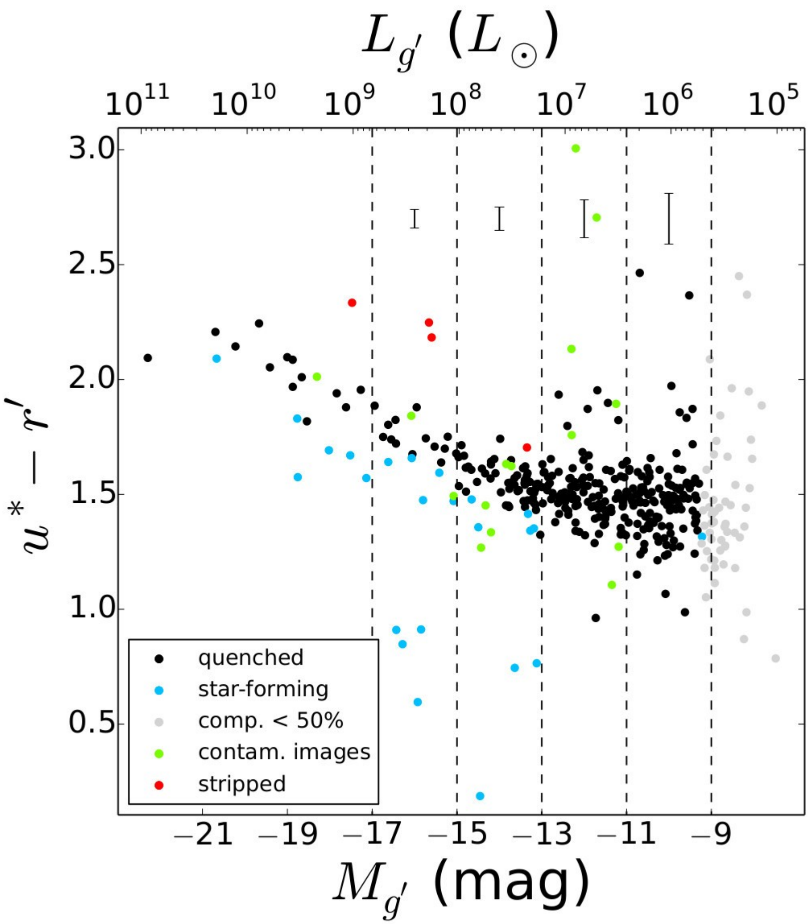
NGFS

Fornax (FDS) – Galaxy density distribution





The Color-Magnitude Relation / Red Sequence



(Roediger et al. 2017, Virgo Cluster, NGVS Collaboration, Inner 2x2 degrees)

Questions:

- What is the scatter along the CM relation, how many objects still need to reach the red sequence?

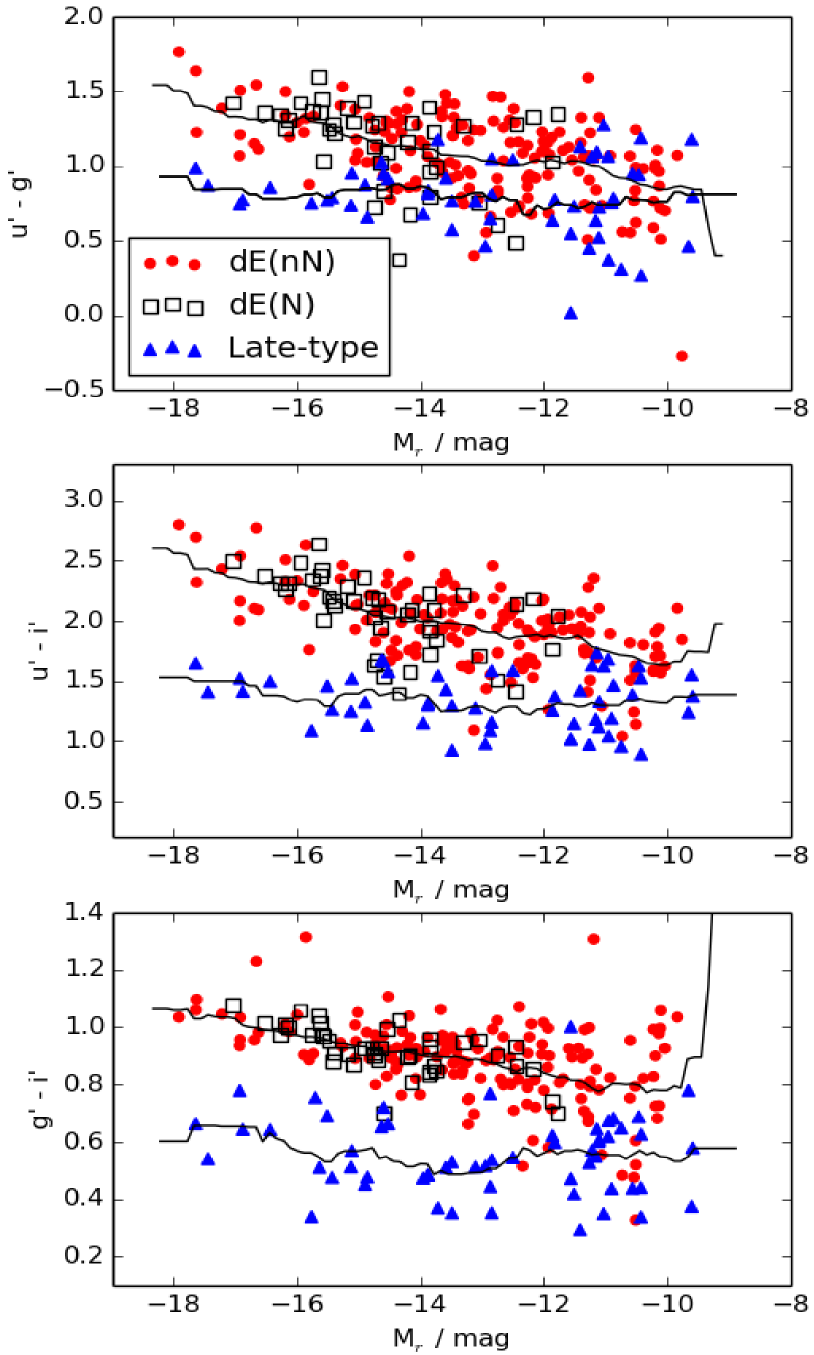
- What is the shape of the CM relation? Roediger et al. Claim it is an S-shape. Why this shape?

- How does the CM relation change as a function of environment?

- What is the fraction of galaxies below (young) and above (compact) the red sequence?

- Is it different for nucleated and non-nucleated galaxies?

The Color-Magnitude Relation in Fornax (FDS)



Questions:

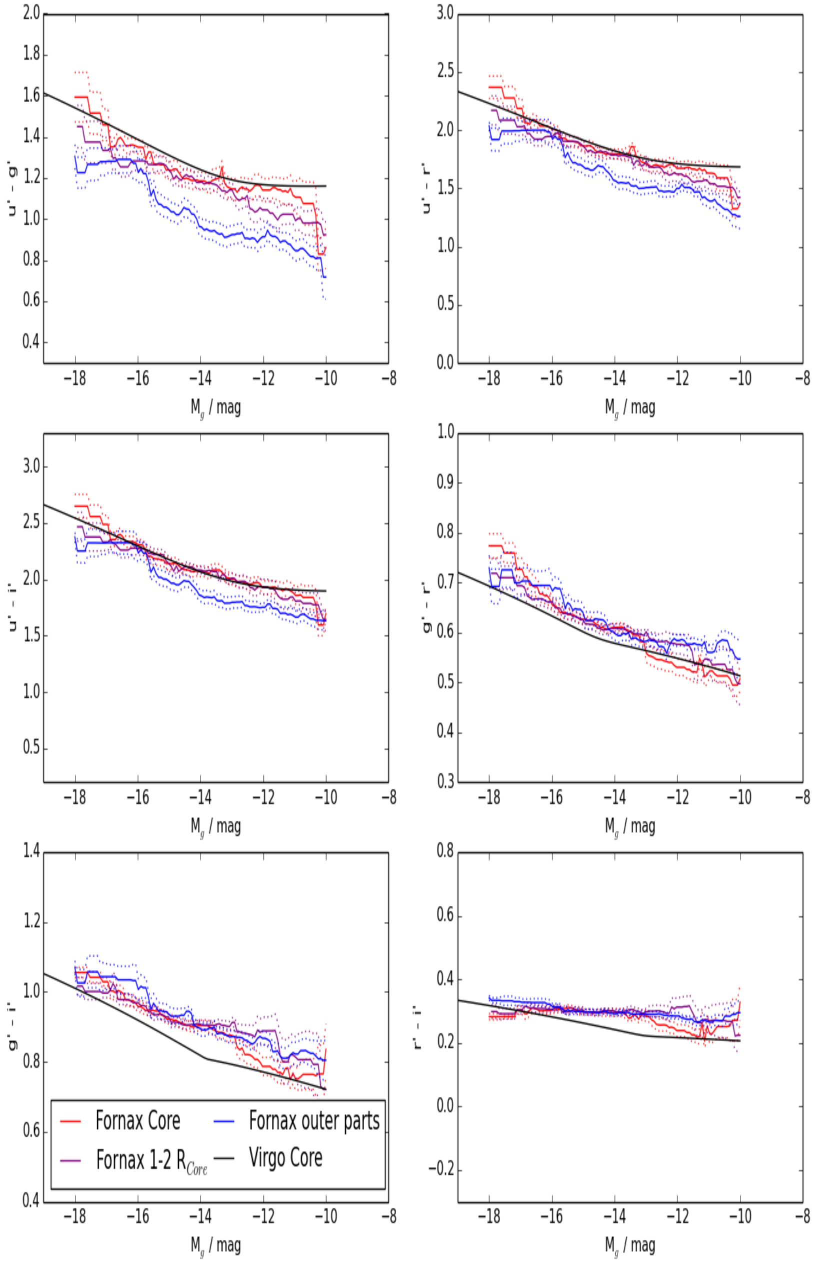
- What is the scatter along the CM relation, how many objects still need to reach the red sequence?

The cluster shows a tight CM relation, becoming less tight towards fainter magnitudes, similar to Virgo. The scatter seems, however, larger, although here we are comparing the whole Fornax Cluster with the center of Virgo.

- What is the fraction of galaxies below (young) and above (compact) the red sequence?

A few compacts above the relation, but many more irregular dwarfs (classified morphologically) than in Virgo. But again, we compare the whole Fornax Cluster with the center of Virgo.

The Color-Magnitude Relation – Comparison with Virgo



Questions:

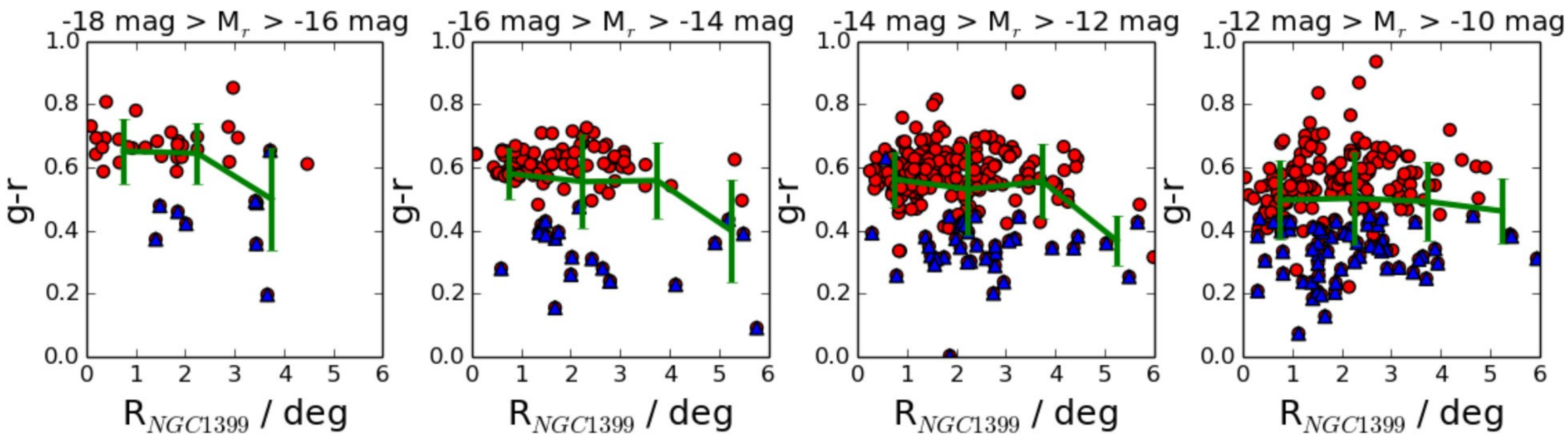
- What is the shape of the CM relation? Roediger et al. Claim it is an S-shape. Why this shape?

In Fornax we see the same shape.

- How does the CM relation change as a function of environment?

It becomes slightly bluer from inner to outer parts (probably due to a combination of age and metallicity.

The Color-Magnitude Relation – Radial Dependence



The color-mag relation itself does not change much from inner to outer parts, but what changes is the fraction of irregular dwarfs.

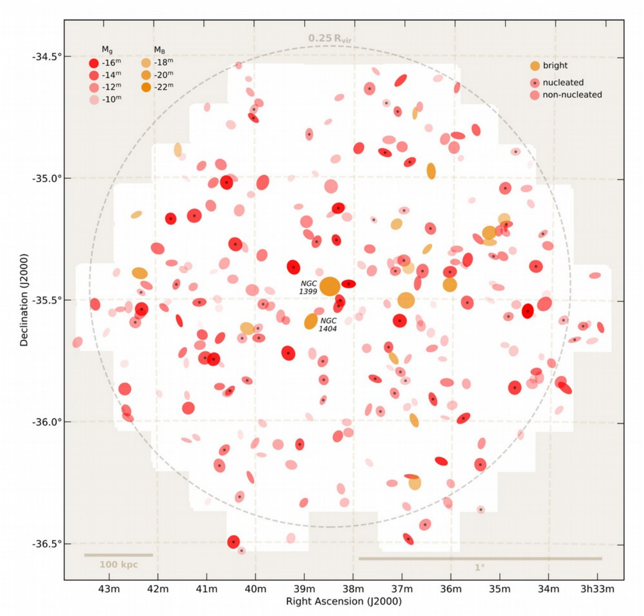
The NGFS Survey

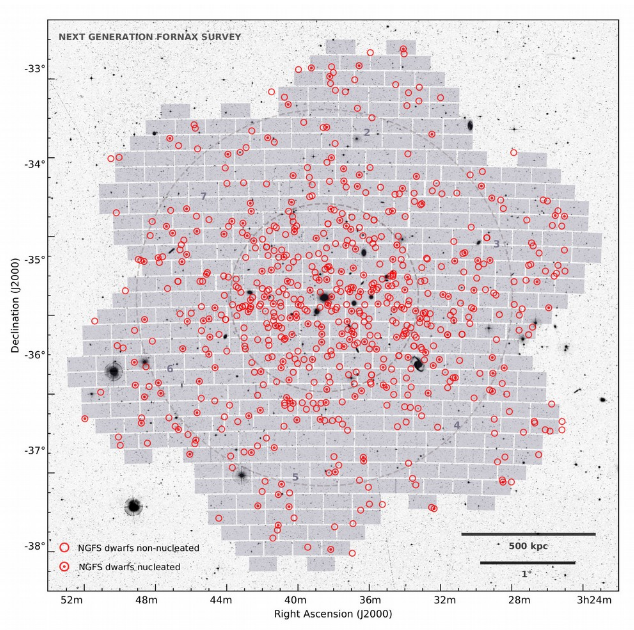
(Eigenthaler et al. 2018
Ordones-Briceno 2018ab)

- 258 dwarf galaxies in inner $r_{vir}/2$, 643 dwarfs in whole area
- Selection by eye

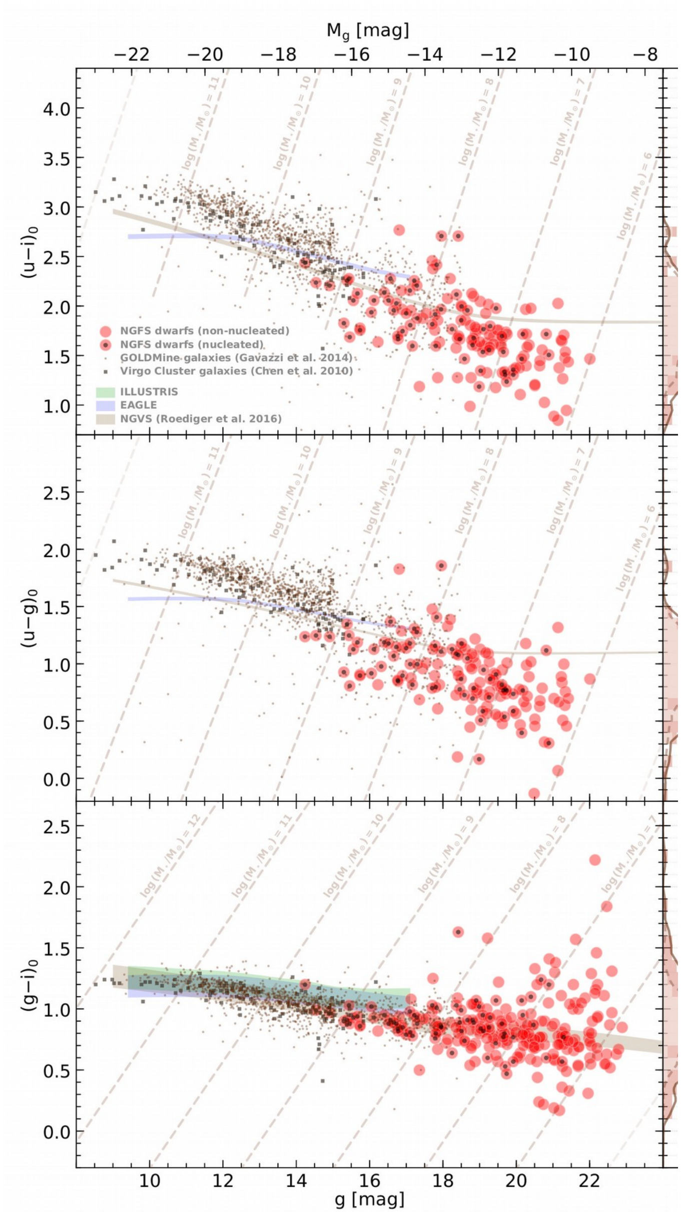
- Comparison difficult, since they include ultra-diffuse galaxies, which we don´t, if we don´t find them automatically. Still ongoing.

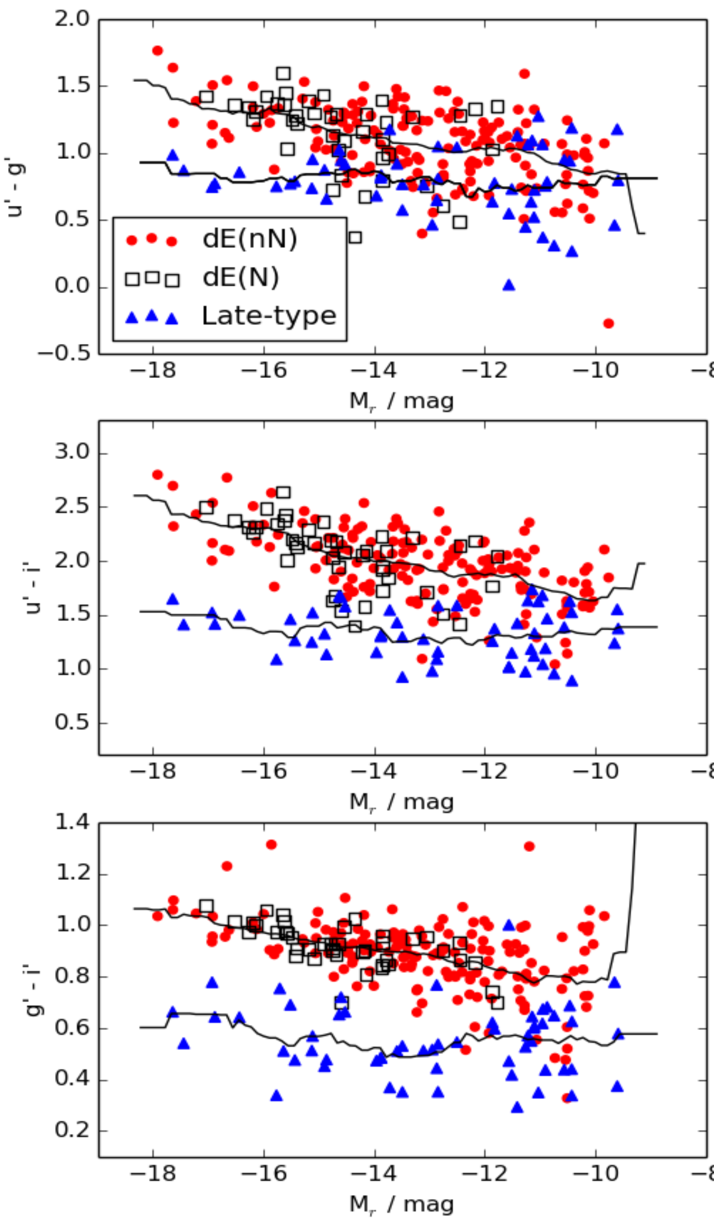
- N1316 area not covered





The Color-Magnitude Relation – Comparison with NGFS

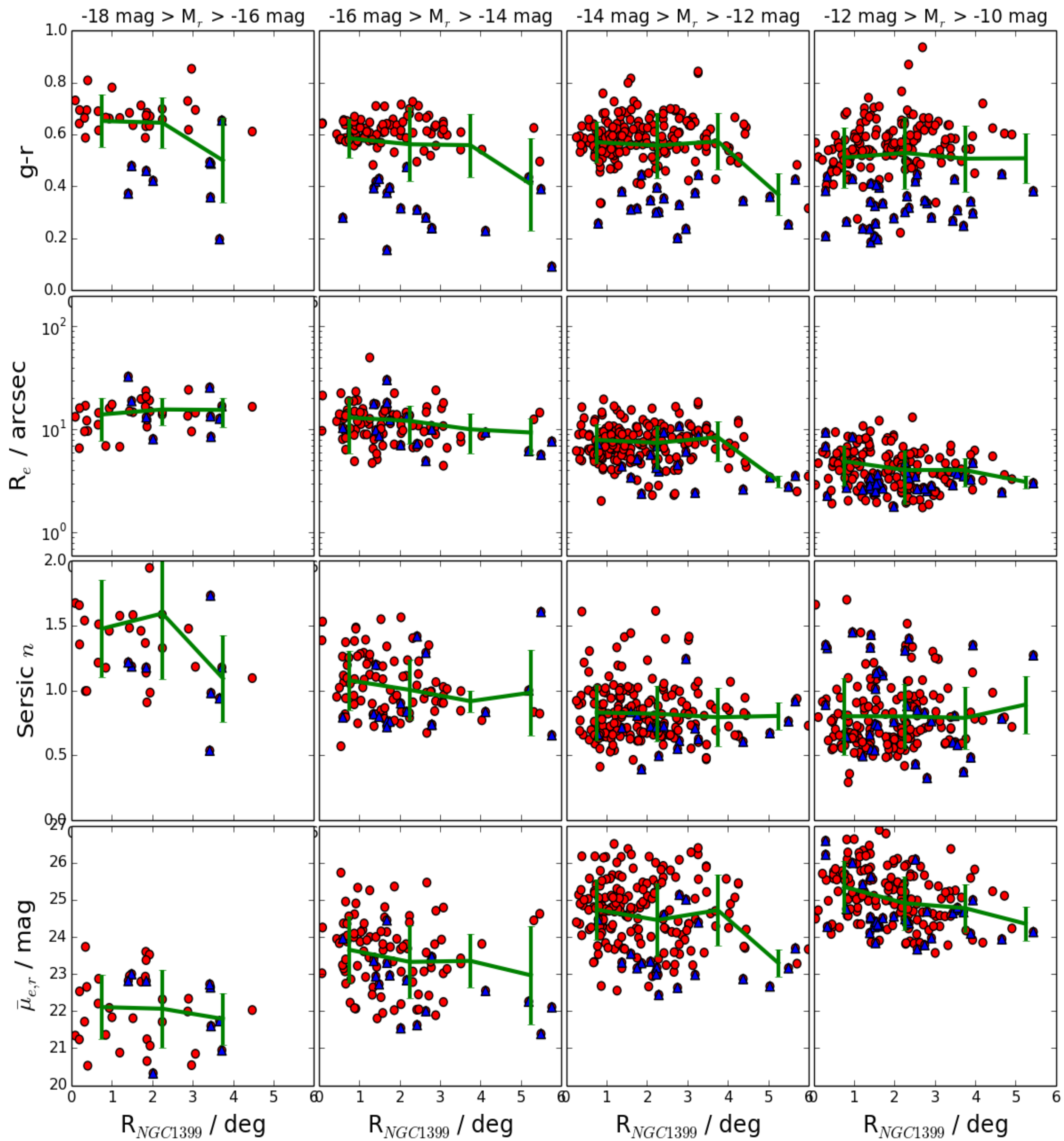




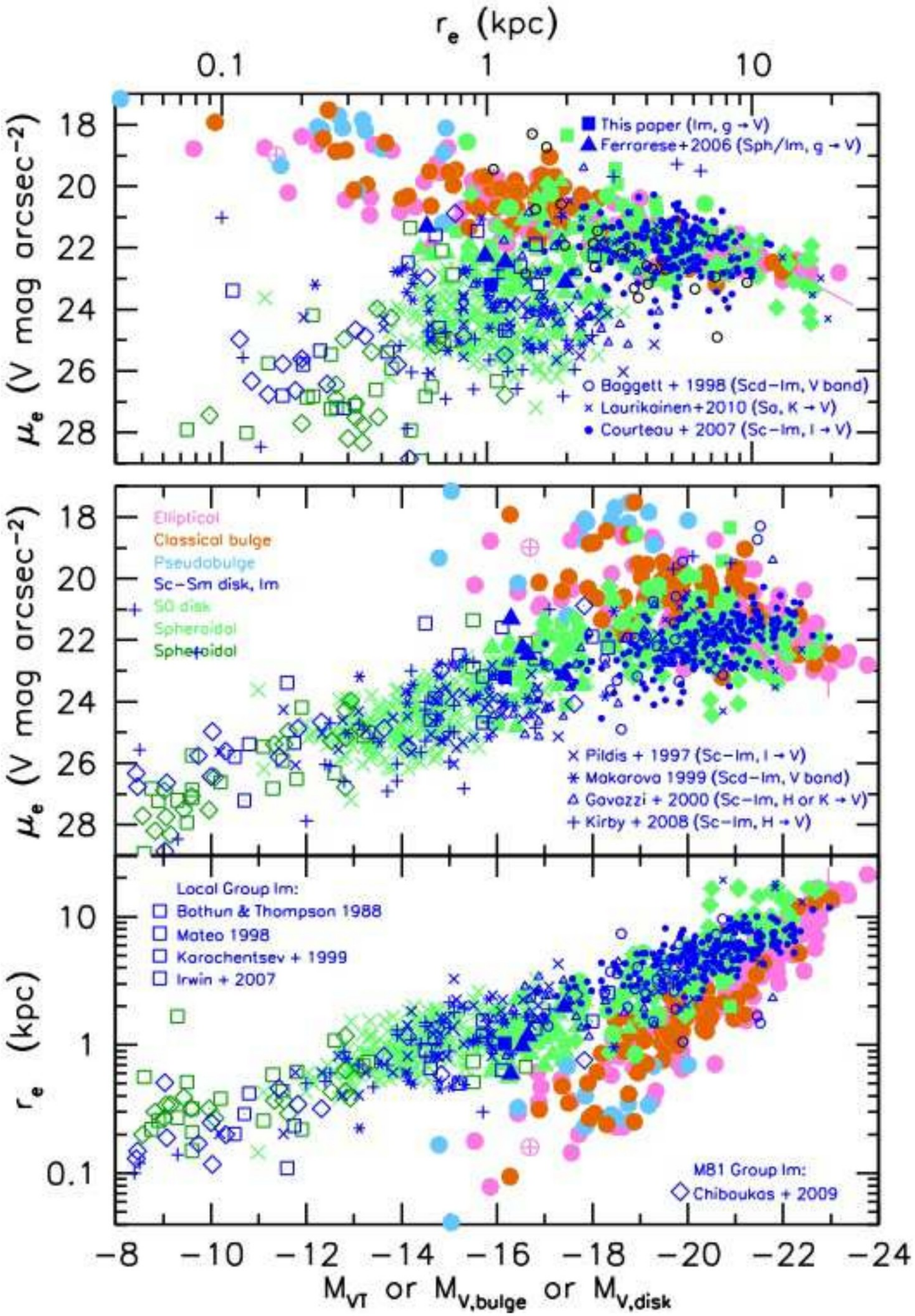
- Fewer irregular galaxies in NGFS (probably since they only cover the central area.
- Possibly an offset in the NGFS photometry at M_g=-16
- Detailed comparison to be made.
- Is it different for nucleated and non-nucleated galaxies?

Probably not.

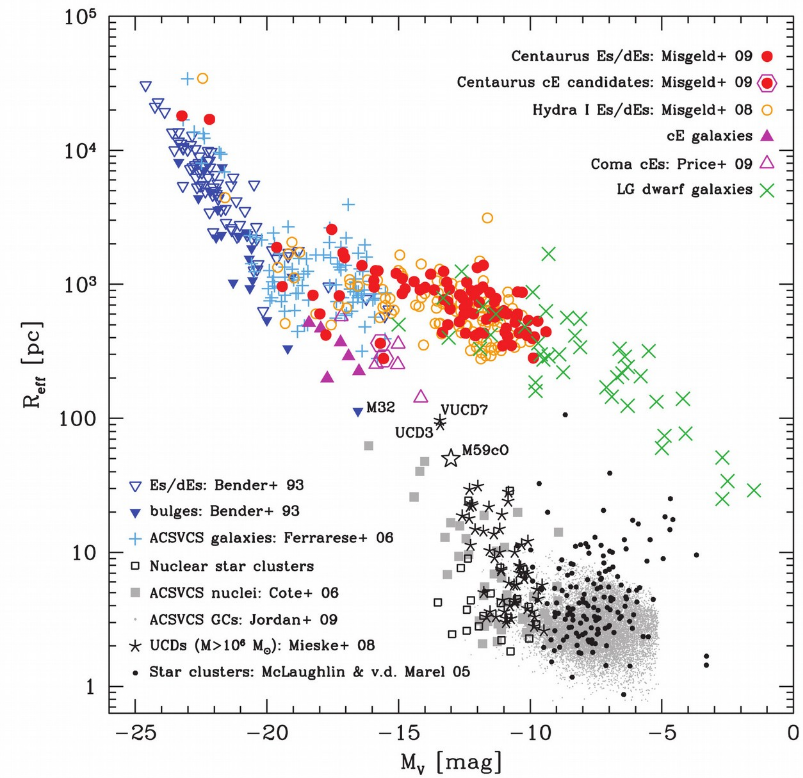
Galaxy Properties as a function of clustercentric distance



Scaling Relations – Kormendy Relations

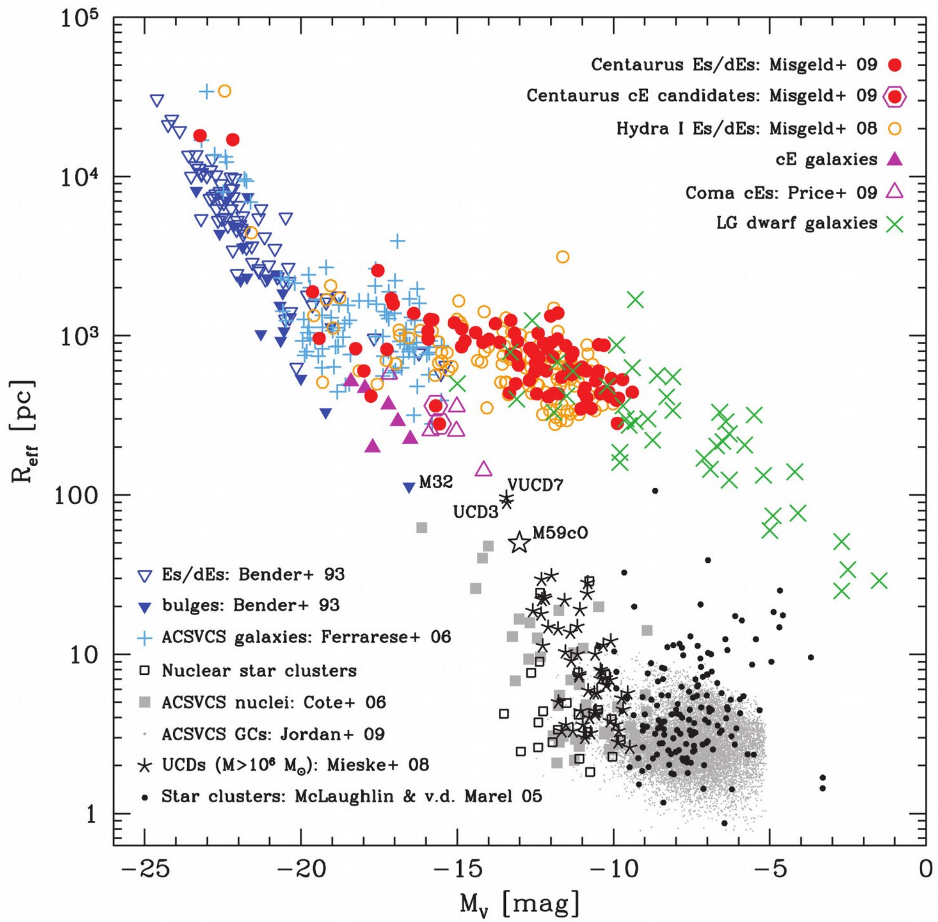


(Kormendy 2012)

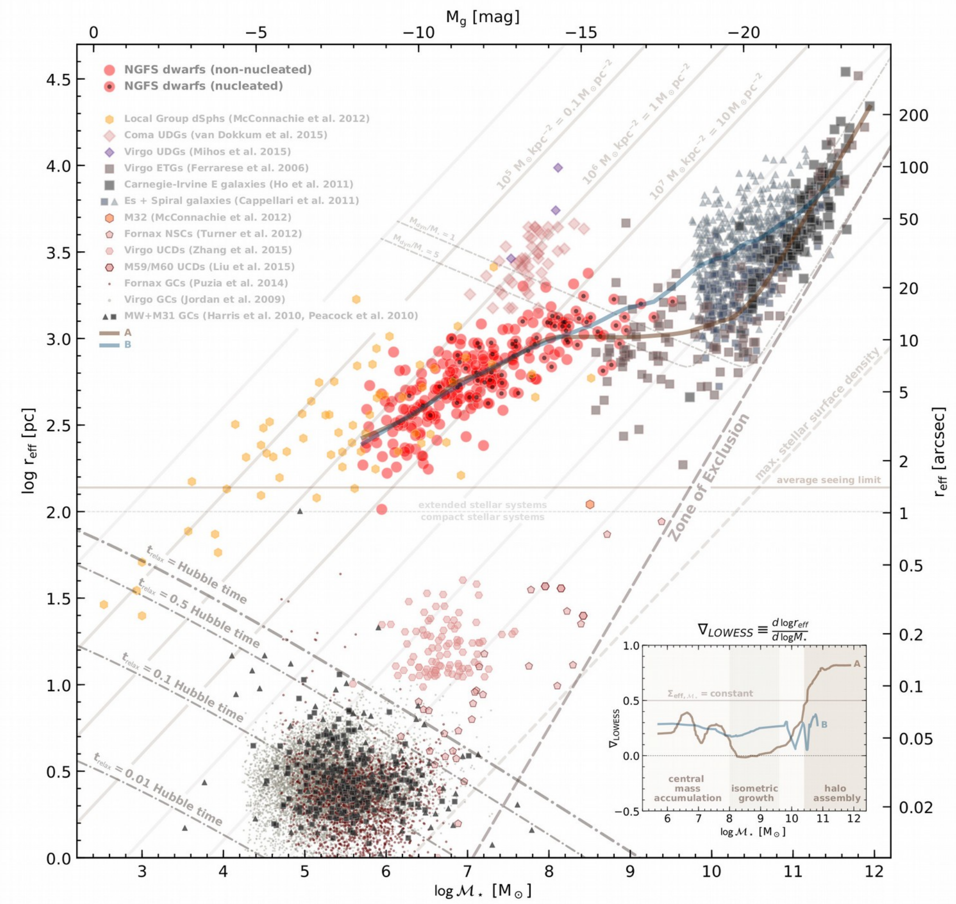


(Misgeld & Hilker 2011)

Quiescent dwarfs are in the same region as star forming dwarfs.

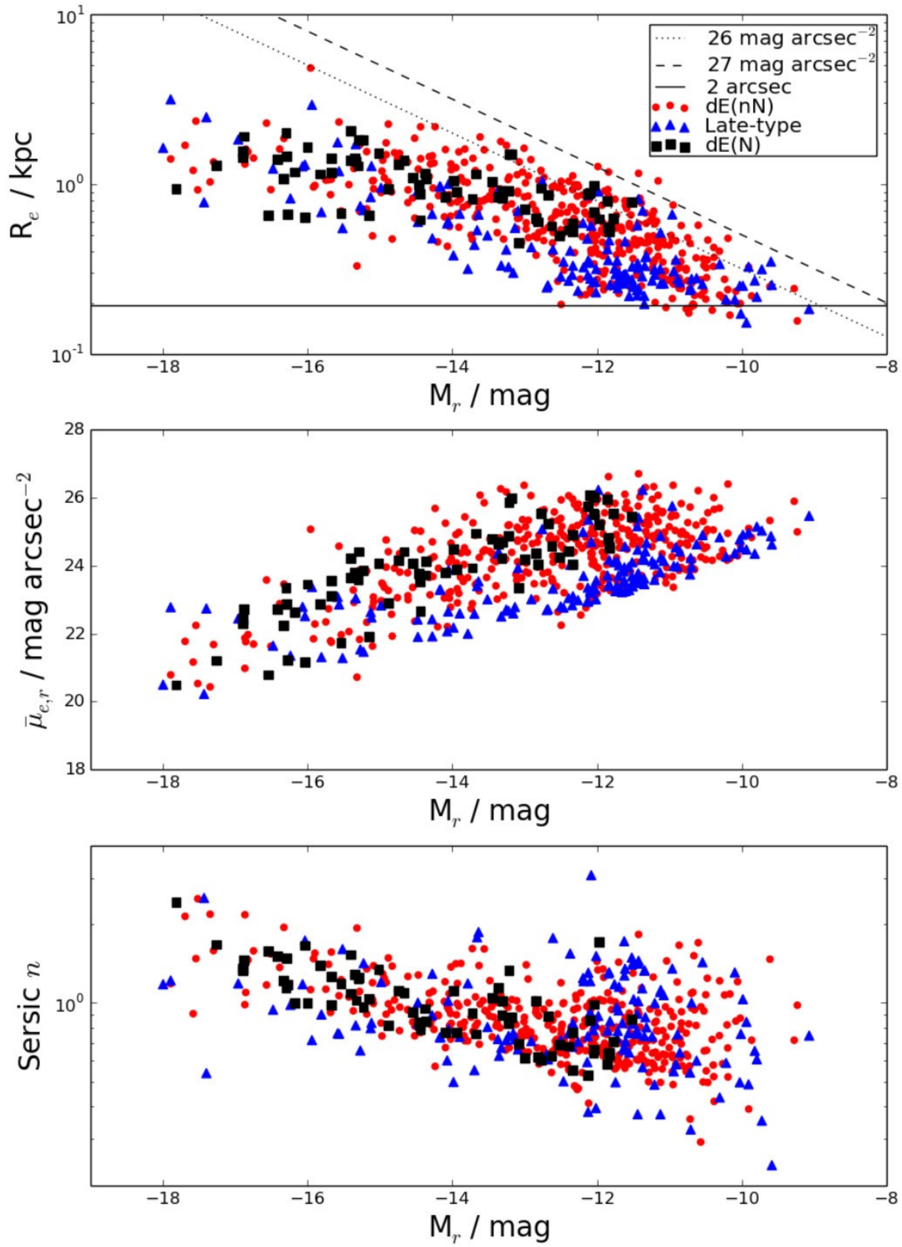


(Misgeld & Hilker 2011)



(Eigenthaler et al. 2018 - NGFS)

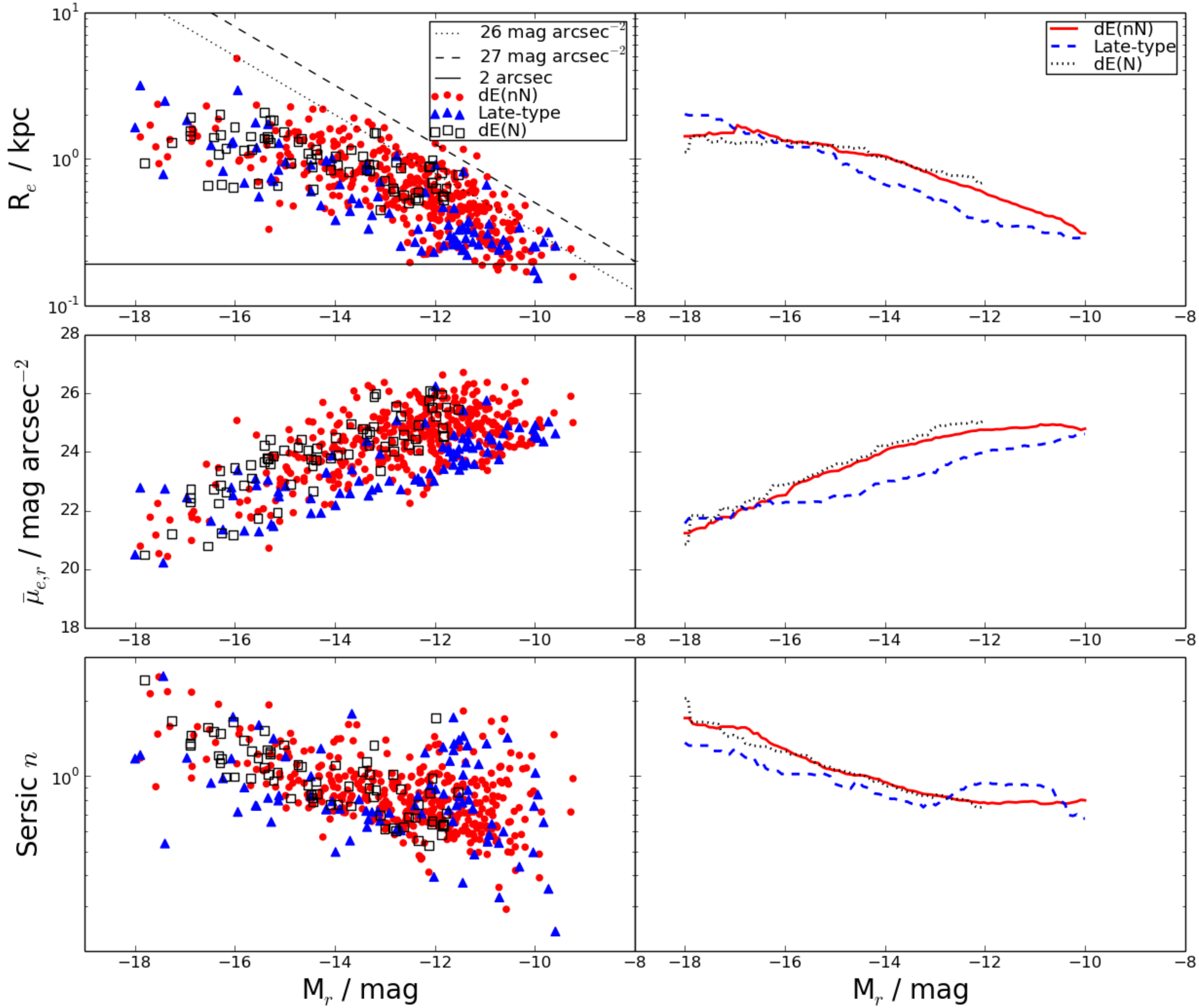
Kormendy Relations in Fornax



- Dwarf galaxies in Fornax show tight scaling relations, consistent with other clusters.

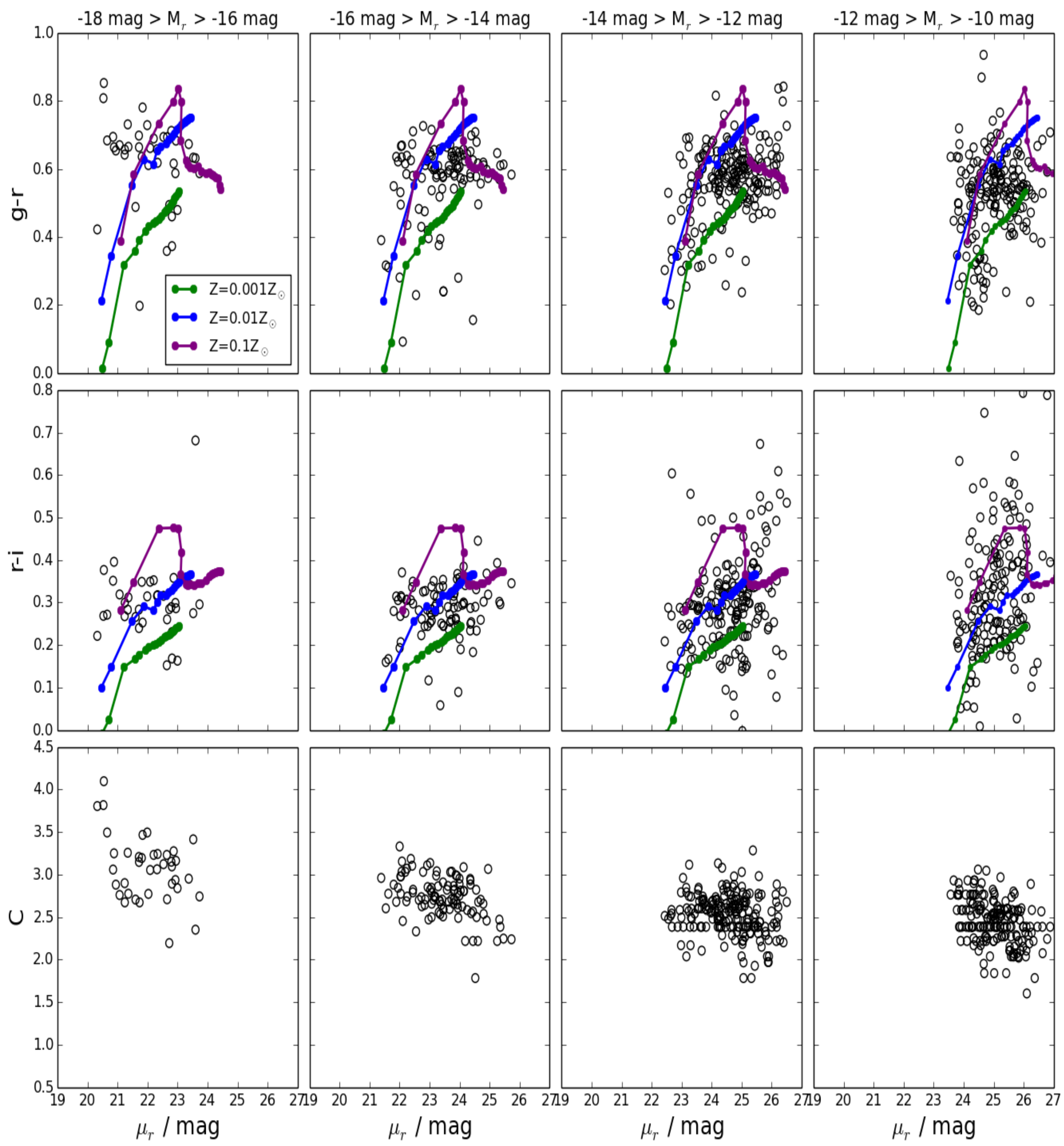
- Nucleated and non-nucleated dwarfs show similar behavior

- Irregular dwarfs behave differently from dwarf ellipticals, being smaller, and having higher surface brightness, but with similar Sersic indices.
  This is consistent with a picture that these irregulars fade into dwarf ellipticals, once their gas has been removed.



26 mag arcsec^{-2}
27 mag arcsec^{-2}
2 arcsec
dE(nN)
Late-type
dE(N)
R_e / kpc
$\bar{\mu}_{e,r}$ / mag arcsec^{-2}
Sersic n
M_r / mag

Scaling Relations as a function of magnitude



Lines show a galaxy fading (using MILES models with time changing along the line). Different colors indicate different metallicities.

To conclude: this analysis is very preliminary, and still needs work.

However, we find that the Fornax cluster is very different from the center of the Virgo Cluster, with more dwarf irregulars. We also find that these objects have scaling relations that are not the same as those of dwarf ellipticals.

Science with the FDS

A. Only FDS (until now)

1. Globular Clusters in Fornax (d'Abrusco et al. 2016)

2. The halo of NGC 1399 (Iodice et al. 2016)

3. Deep photometry of the merger remnant NGC 1316 (Iodice et al. 2017)

4. Ultra Diffuse Galaxies in the core of the Fornax Cluster (Venhola et al. 2017)

5. Intracluster Light in the Core of the Fornax Cluster (Iodice et al. 2018)

Science with the FDS

B. Science in progress, including followup and complementary projects

6. Complete census of dwarf galaxies in Fornax down to M_r=-10 (Venhola)

7. Stellar population studies of a dwarf elliptical with MUSE (Mentz et al. 2016)

8. Deep IFU spectroscopy of a complete sample of Fornax dwarf galaxies using the SAMI spectrograph at R=5000 (with Nic Scott, Sara Eftekhari, Steffen Mieske)

9. Neutral Hydrogen (HI) survey using MeerKAT (P.I. Paolo Serra)

10. ALMA CO-followup (P.I. Tim Davis)

11. Planetary nebulae in the Fornax Cluster (Spiniello)

12. Machine learning applications (SUNDIAL project)

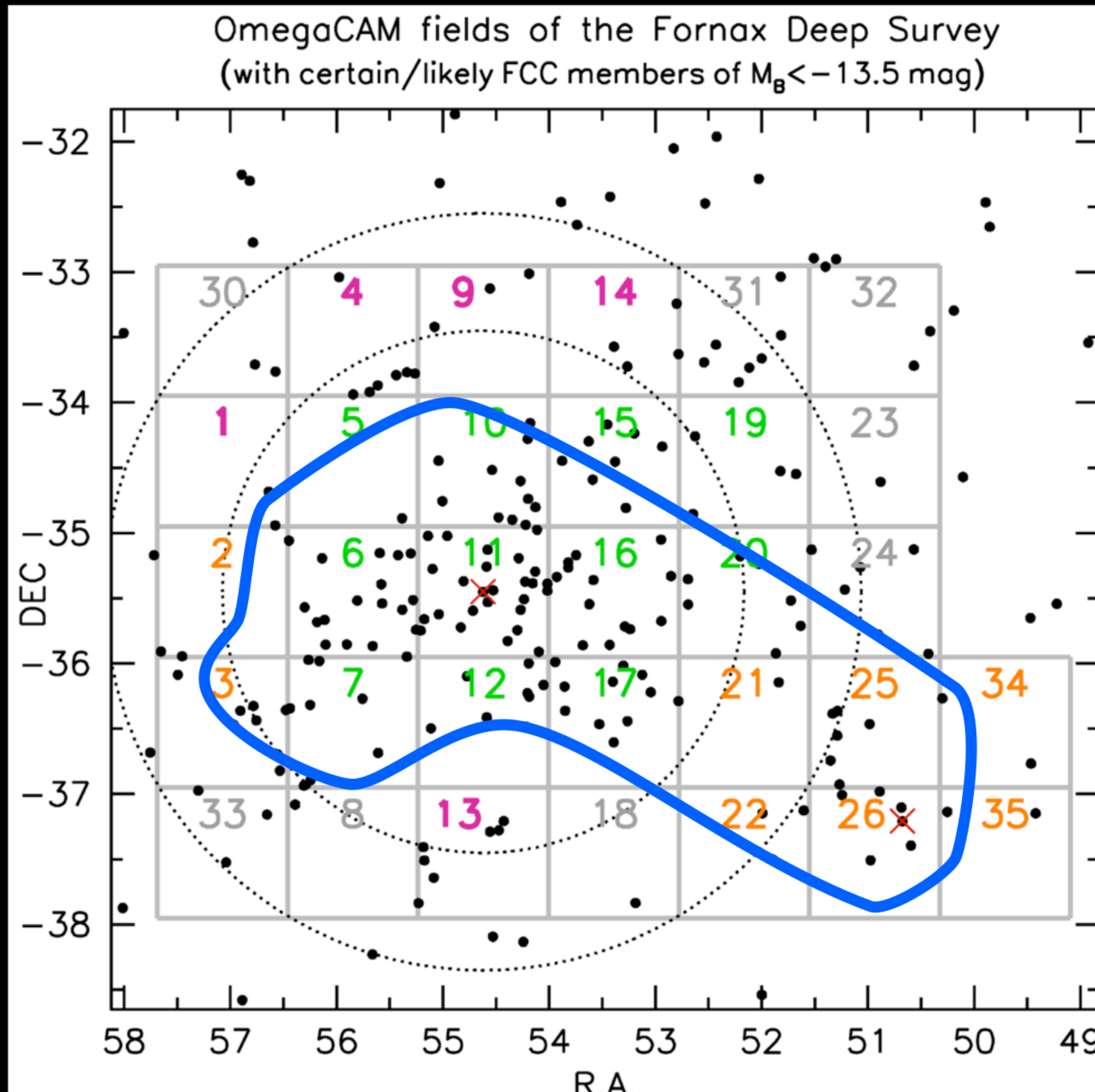
13. Automated detection of faint galaxies (UDG etc.) (SUNDIAL project)

14. Cluster evolution simulations (Lead: Sven de Rijcke)

15. UV Followup (with the UVIT telescope)

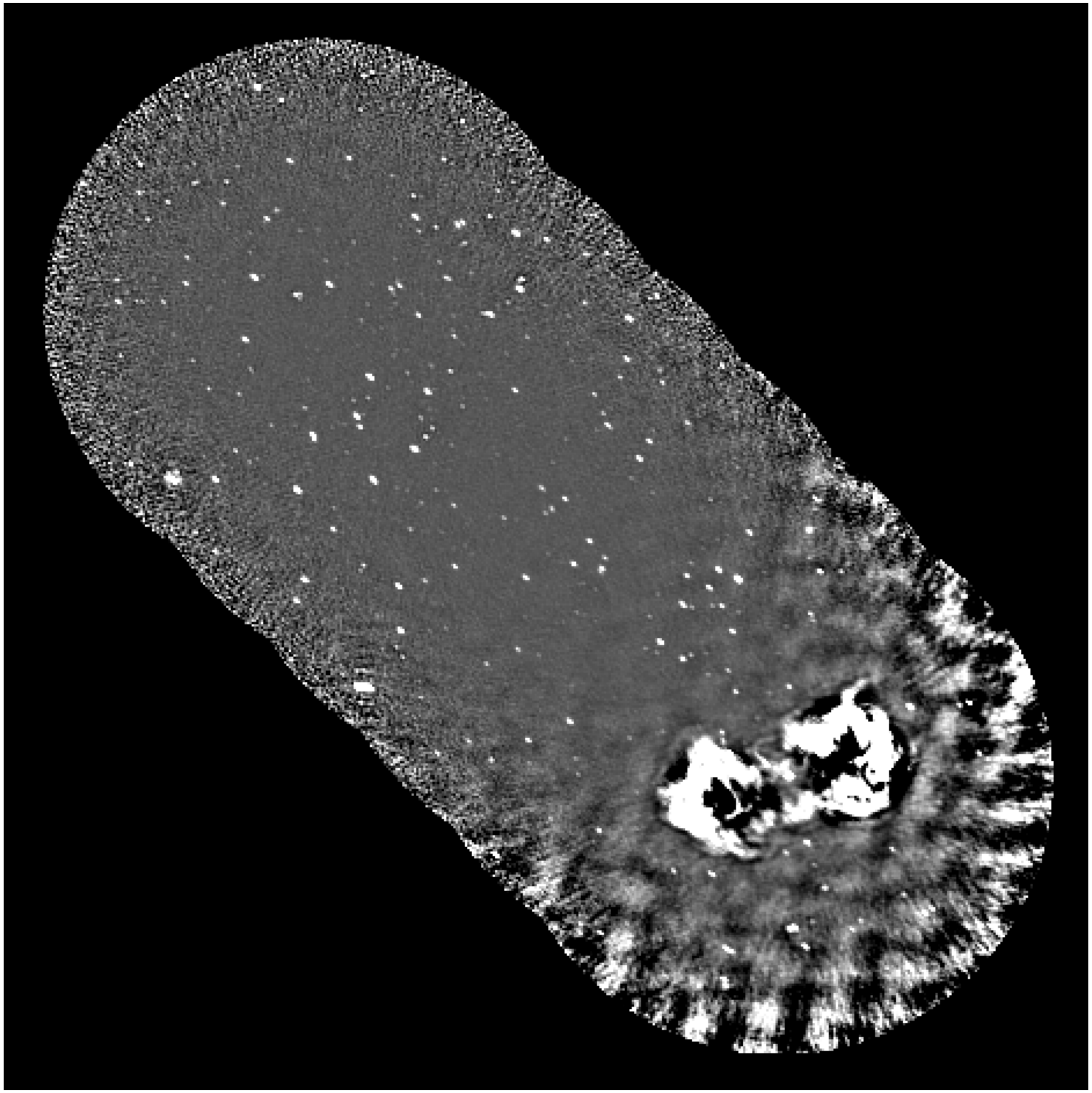
16. Several other topics, including near-infrared imaging (VISTA), globular cluster studies, outer regions of massive galaxies, intracluster light, membership determination, UCDs etc.

The Meerkat Fornax Survey (P.I. P. Serra)



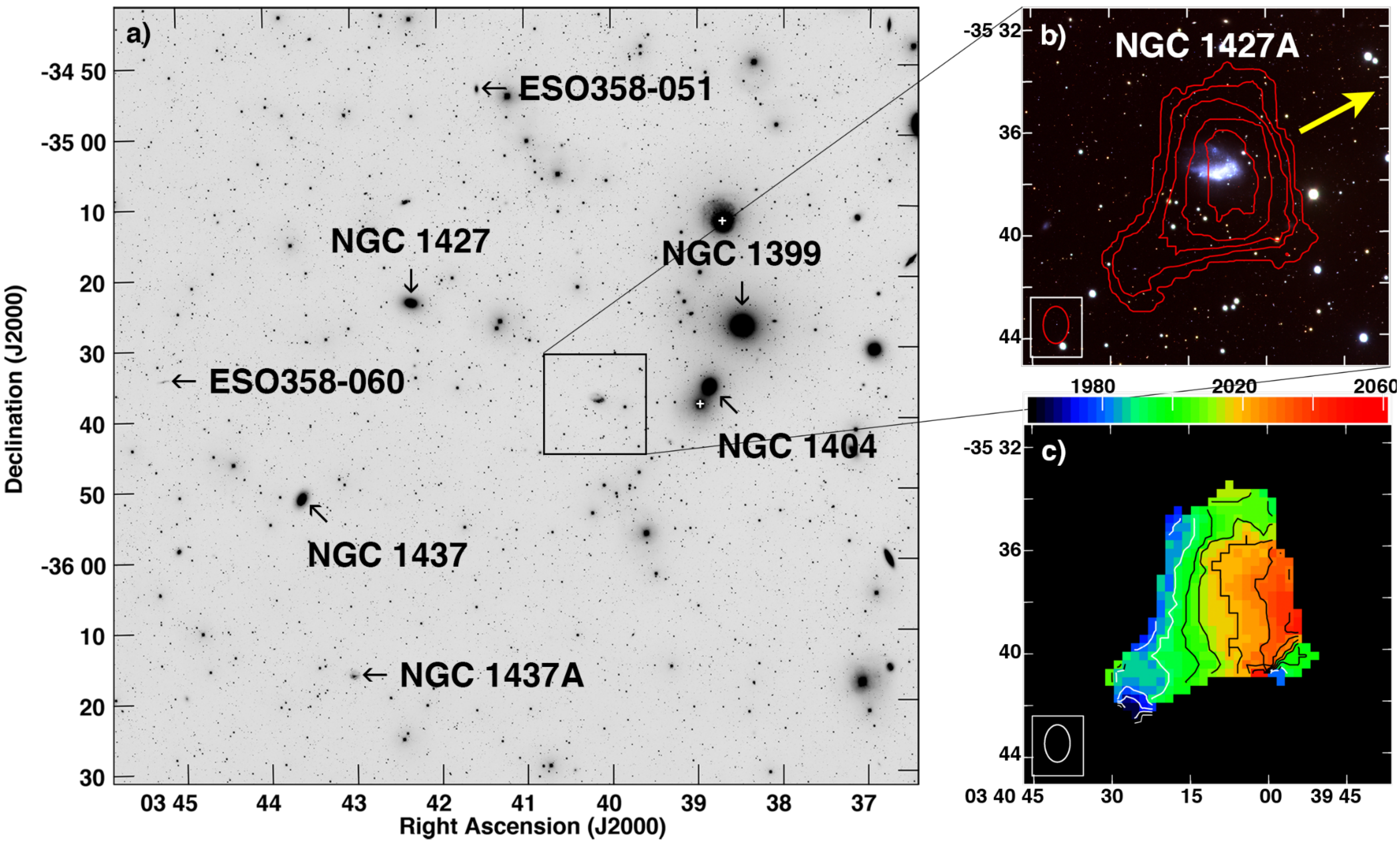
Blue: HI coverage (Meerkat)

MEERKAT HI Commissioning (from yesterday!)



Field size
appr. 3X3 deg

Credits: Filippo Maccagni (as part of the MeerKAT Fornax team)
and to the MeerKAT commissioning team.



a)
ESO358-051
NGC 1427
NGC 1399
ESO358-060
NGC 1404
NGC 1437
NGC 1437A
-34 50
-35 00
10
20
30
40
50
-36 00
10
20
30
Declination (J2000)
03 45
44
43
42
41
40
39
38
37
Right Ascension (J2000)
b)
NGC 1427A
-35 32
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40
44
1980
2020
2060
c)
-35 32
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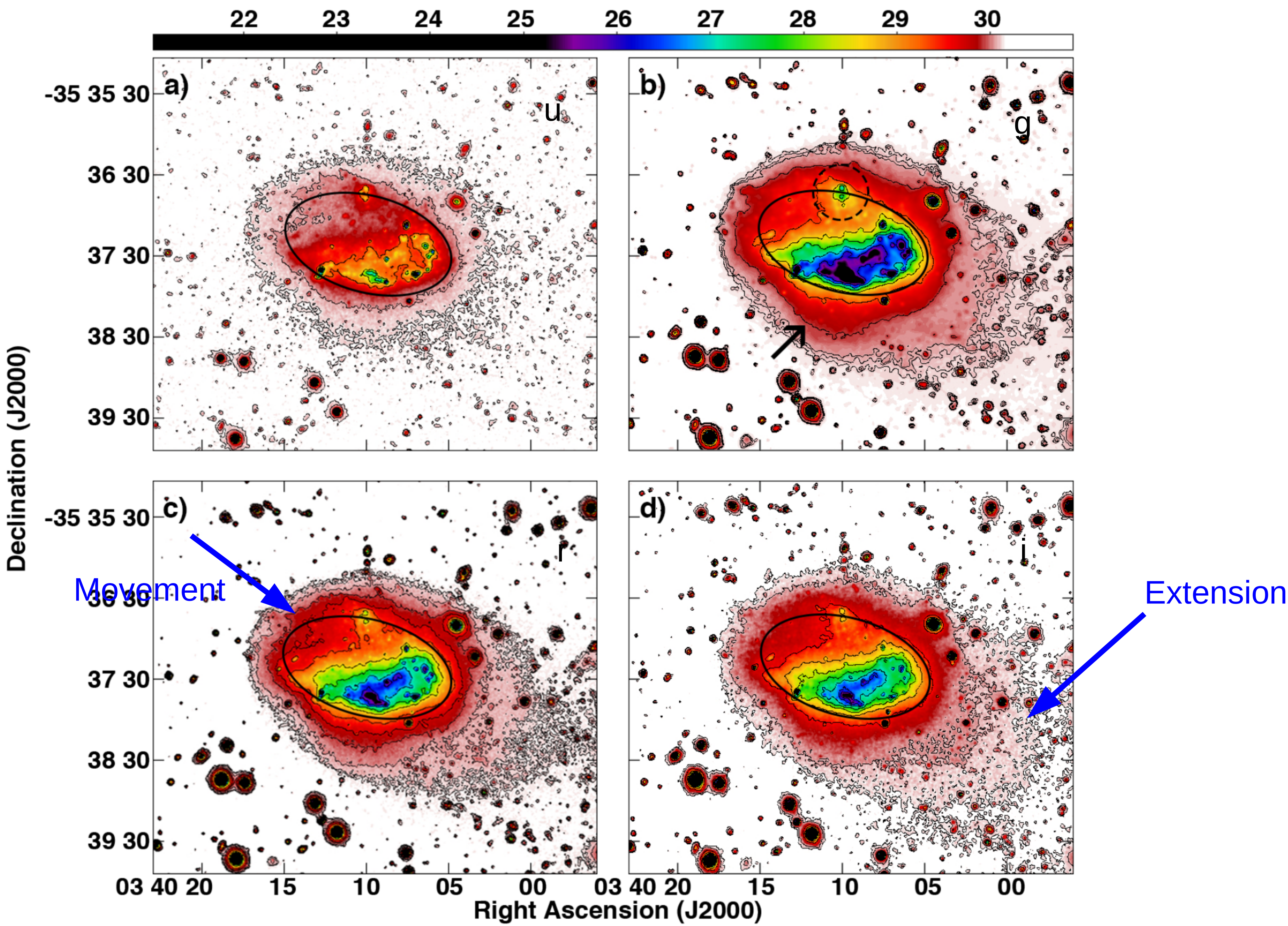
40
44
03 40 45
30
15
00
39 45

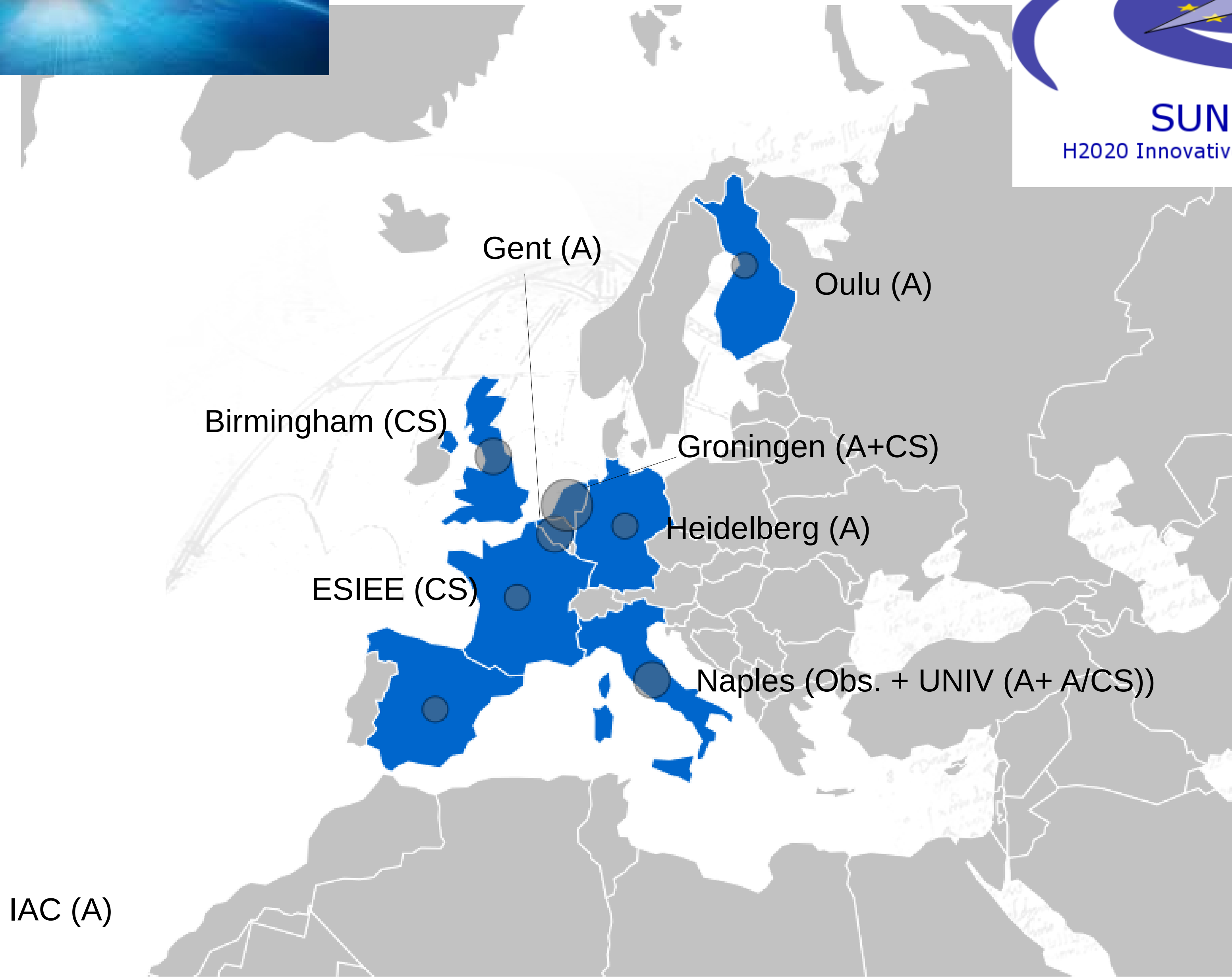


Extension on side towards which the galaxy should move argues against ram pressure stripping!

SUNDIAL ITN

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION
HORIZON 2020

SUNDIAL
H2020 Innovative Training Network



Aims of network:

Interdisciplinary collaboration of astronomers and computer scientists to determine novel algorithms to study galaxy evolution. In particular:

(1) **Automatic detection of faint low surface brightness galaxy features** (dwarf galaxies, merger remnants, intracluster light) in deep astronomical surveys, and interpreting them astrophysically in terms of galaxy formation and evolution.

(2) Automated object recognition in Big Data sets: (a) the unsupervised identification of groups of objects with similar properties (**clustering**) and (b) the supervised assignment of objects into pre-defined target classes (**classification**). The addition of **prior information** from astrophysics will be crucial in both cases.

(3) **Simulations** of galaxy interactions, their **characterisation** and **visualisation.** The simulations serve to identify the critical characterisation, necessary to optimally identify how observations can be described. Such comparisons will lead to a better parametrisation and understanding of galaxy cluster evolution.